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Costs and National Noise Impact of Feasible Solution Sets for Reduction of Airport Noise

Wyle Labs, El Segundo, Calif

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16. ABSTRACT

The purpose of this study was to determine the effectiveness and costs associated with feasible solution alternatives for the reduction of cumulative noise impact from airport and aircraft operations. Results of the analysis will be used in a separate study for assessing economic impact under a variety of financing schemes and at different levels of noise reduction in support of the proposed airport noise regulatory program initiated under the Noise Control Act of 1972.

Solution sets considered encompass aeronautical alternatives, operational alternatives, and receiver alternatives. Specific costs, in terms of 1975 dollars, are given for the aeronautical and receiver alternatives. Except for the 6°/3° approach, the operational alternatives are treated as zero cost options for this study.

Source noise and operational noise reduction methods were tested against individual civil air carrier airports and airport models derived from representative airport samples for current and future time periods. Future aircraft fleet projections considered new trends indicated by the current energy shortage; evaluation of people impacted in the future allowed for a fixed population growth around all airport environs. Effectiveness of the various noise reduction methods was evaluated in terms of noise impact area, population, and land and housing value data determined for individual airports, three representative airport categories, and 514 air carrier airports. All noise impact results were calculated in terms of L_{dn} levels and Noise Units. These data, in conjunction with cost factors associated with the various noise reduction schemes, provide the parameters by which an economic impact assessment can be conducted.

The noise impact of over 6600 general aviation airports in the U.S. was estimated in a similar but less comprehensive manner.

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1.0 INTRODUCTORY SUMMARY

1.1 Introduction

The purpose of this study was to determine the effectiveness and costs associated with feasible solution alternatives for the reduction of cumulative noise impact from airport and aircraft operations. Results of the analysis will be used in a separate study for assessing economic impact under a variety of financing schemes and at different levels of noise reduction in support of aircraft/airport noise reduction programs initiated by the U.S. Environmental Protection Agency under the Noise Control Act of 1972.

Solution sets considered encompass:

1. Aeronautical alternatives (i.e., sound absorption material (SAM) treatment of nacelles, REFAN retrofit, and FAR 36-10 design for new aircraft).
2. Operational alternatives (i.e., modified approach profile, power cutback on takeoff, and night curfews).
3. Receiver alternatives (i.e., noise reduction treatment of homes or relocation of residents).

Specific costs, in terms of 1975 dollars, are given for all these noise reduction alternatives. Except for the 6°/3° approach, the operational alternatives are treated as zero cost options for this study.

Source noise and operational noise reduction methods were tested against individual civil air carrier airports and airport models derived from representative airport samples throughout the U.S. for current and future time periods. Future aircraft fleet projections considered new trends, indicated by the current energy shortage; evaluation of people impacted in the future allowed for a fixed population growth around all airport environs. Effectiveness of the various noise reduction methods was evaluated in terms of noise impact area, population, and land and housing value data determined for individual airports, three representative airport categories, and 514 air carrier airports in the nation as a whole. All noise impact results were calculated in terms of L_{dn} levels and Noise Units* (a weighted measure of the number of people impacted). These data, in conjunction with cost factors associated with the various noise reduction schemes, provide the parameters by which an economic impact assessment can be conducted.

The noise impact of over 6400 general aviation airports in the U.S. was estimated in a similar but less comprehensive manner.

1.2 Summary of Results

An abbreviated summary of the essential results of this study is given in Table 1-1. This table lists the following parameters for each of the air carrier airport noise reduction alternatives considered for the year 1987, along with a baseline case for 1972. (Results for the intermediate year 1981, included in this study, show similar trends.)

- Total population impacted
- Total Noise Units
- Change (Δ) in Noise Units relative to base condition for year indicated
- Total cost (where applicable) of alternative
- Cost-effectiveness Index (ΔNU/$M)

---

*The Noise Unit scale may be considered as defining the equivalent number of people exposed to a uniform total L_{dn} value, 20 dB above the criterion noise level around the airport. The criterion level is equal to an L_{dn} of 55 dB or the estimated ambient L_{dn} (without aircraft) based on population density, whichever is higher. The scale is constructed so that if the criterion level is, say, 60 dB, then 200 people exposed to an L_{dn} of 70 dB, or 100 people exposed to an L_{dn} of 80 dB, or 67 people exposed to an L_{dn} of 90 dB would, in each case, be equivalent to 100 Noise Units. That is,

$$200 \times (70-60)/20 = 100 \times (80-60)/20 = 67 \times (90-60)/20 = 100 \text{ Noise Units}$$

The label "Equivalent Noise Impact" (ENI) has also been applied to Noise Units.

Table 1-1

Summary of Cost-Effectiveness of Air Carrier Airport Noise Reduction Solution Sets

Year	Alternative	Total Population Impacted⑥	Total Noise Units⑥	Change in Noise Units①	Total Cost	Cost-Effectiveness
		X1000	X1000	X1000	\$M	ΔNU(1000)/\$M
1972	Base	7089.5	4991.4	–	–	–
1987	Base	5904.9	3631.9	–	–	–
Operational	Power Cutback	5479.3	3770.7	(138.8)	–	–
	4° Approach	4614.8	3443.3	188.6	–	–
	6°/3° Approach	4581.9	3286.9	345.0	78.0	4.42
	Curfew A②	2491.5	1748.6	1883.3	–	–
	Curfew B③	2199.3	1525.9	2106.0	–	–
Aeronautical	SAM 3D/8D	4060.7	2917.7	714.2	741.8	0.96
	REFAN 8D/SAM 3D	1960.9	1360.0	2271.9	3051.6	0.74
	FAR 36-10④	4762.9	3349.0	282.9	–	–
	Composite⑤	2591.9	1885.0	1746.9	819.8	2.13
Receiver	Residential Noise Red. dB −5	2408.7	1146.7	2485.2	7297.0	0.34
	−10	413.8	239.5	3392.4	11,308.0	0.30
	−15	65.4	44.2	3587.7	12,583.0	0.29
	Relocate All Inside L_{dn} 85	5101.4	3626.1	5.8	25.4	0.23
	75	4891.1	3134.7	497.2	2662.4	0.19
	65	0	0	3631.9	25,754.0	0.14

Notes:

① ΣNU relative to base for year indicated
② Night flights rescheduled to daytime (7AM – 10PM)
③ Night flights eliminated
④ FAR 36-10 for new aircraft after 1981
⑤ 6°/3°, PCB, SAM 3D/8D and FAR 36-10 for new aircraft after 1981
⑥ Inside the L_{dn} 65 contour at all the nation's air carrier airports

Although no attempt was made to optimize the large array of possible solution sets, it seems clear that in the near term the most cost-effective solutions to the noise around air carrier airports would include the use of the 6°/3° glide slope, which produces a small decrease in Noise Units at a low cost, combined with the SAM 3D/8D retrofit alternative. The latter appears to be substantially more cost-effective than other aeronautical alternatives or any of the receiver alternatives. Further evaluation is needed, however, to determine if even more cost-effective scenarios exist and to establish financing strategies.

An overall graphic illustration of the trend in cost versus effectiveness, measured in terms of the reduction (Δ) in Noise Units, is presented in Figure 1-1. Reflected are all of the alternatives analyzed in this study except the power cutback and curfew alternatives for the year 1987. As one expects, the locus of most cost-effective solutions shows an accelerating slope (higher cost per unit change in Noise Units) for the more effective noise reduction alternatives. The most cost-effective solutions are provided, in general, by the aeronautical and operational alternatives, especially SAM retrofit combined with power cutback and two-segment approach.

The examination of noise impact around most of the nation's general aviation airports did not consider specific noise reduction alternatives other than an arbitrary noise reduction of the business jet fleet by 5 dB for the 1987 period. The basic results of this evaluation indicate the following trends:

For the 1972 baseline condition, the total area inside an L_{dn} 65 contour around all general aviation airports is only about 8 percent of that around all of the air carrier airports. The number of people residing inside this contour, throughout the nation, is estimated to be of the order of 12,000 for the year 1972 (less than 0.2 percent of the number (7.1 million) inside the L_{dn} 65 contour around air carrier airports. However, for the year 1987, the rapid growth of general aviation – especially in business jets – is expected to result in an increase in this impacted population to a total in the order of 180,000 compared to a total population of 5.1 million inside the L_{dn} 65

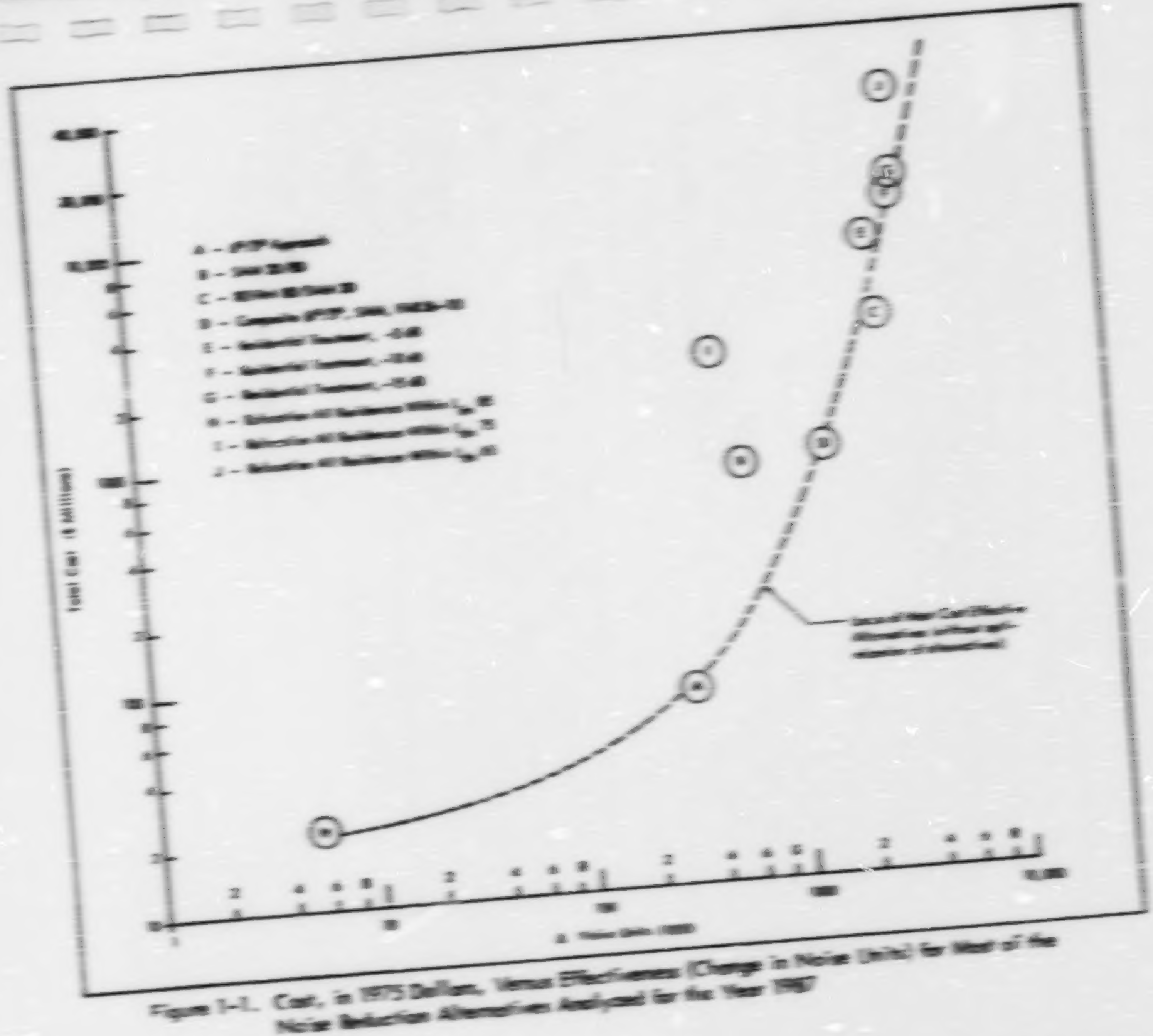

Figure 3-1. Cost, in 1975 Dollars, Versus Effectiveness (Change in Noise Units) for Most of the Noise Reduction Alternatives Analyzed for the Year 1987

contour around air carrier airports by the year 1987. Thus, although the impact around general aviation airports is expected to remain small relative to that around air carrier airports, it may show a very large absolute increase in the future unless substantial noise reduction steps are taken for general aviation aircraft. A 5 dB decrease in the average noise level of the current business jet fleet could reduce the future growth in noise impact around general aviation airports by approximately one-third.

Finally, it should be pointed out that unique analysis tools were developed in the course of this study which can be efficiently applied to the evaluation of costs and noise impact of other airport noise reduction scenarios.

The next section defines the methods used for predicting noise environments and impacted population around the nation's air carrier airports for the noise reduction alternatives considered. Section 3 develops the corresponding information on techniques for predicting costs of these alternatives. Section 4 presents the overall summary of the results of the program in the form of tables on noise impact and costs for all the alternatives. Finally, Section 5 presents the conclusions and recommendations drawn from the study.

Additional details and supporting information for evaluating residential noise reduction and impact around general aviation airports are presented in a series of Appendices at the end of the report.

It should be noted that the number of significant figures carried in the tabular data in this report are maintained for the convenience of the users of the data, and do not necessarily reflect that degree of accuracy of the data.

2.0 STUDY METHOD

This program was conducted in order to define the cost and effectiveness parameters of airport noise reduction alternatives at the national level for air carrier and general aviation airports. The cost data is to be utilized as input to a study of alternate financing strategies of the more cost-effective noise reduction solution sets. Effectiveness of noise reduction was measured in term of the population impacted within L_{dn} contours from 65 to 85 dB.

The broad objectives of the program required a careful selection of each of the study methods involved in order to achieve a reasonable accuracy for the final results within the constraints of the program resources. Later in this section, the noise impact analysis methods used to establish effectiveness of each of the noise reduction alternatives are presented in detail. The next section presents corresponding details of the economic analysis methods. Before getting to these details, however, it is desirable to provide a brief background on the study and to outline the approach taken in completing it.

2.1 Background

Unlike the previous studies upon which this program was based,[1,2]* this program includes a more detailed evaluation of the total impacted population at all of the nation's airports. Land-use changes and residential noise reduction treatment were also included in order to provide a broader spectrum for evaluation of potentially cost-effective airport noise reduction alternatives. Although some consideration of these types of receiver alternatives had been made in a previous background study on airport noise reduction,[3] the analysis was considered to be insufficiently definitive for purposes of this program.

There are other substantial differences in the study elements between this report and the previous reports in the areas of baseline conditions, abatement alternatives, air carrier fleet and operations forecast, consideration of general aviation airports, extrapolation to the nation, and the composite noise scales. These differences are apparent in the summary of the study elements of each program shown in Table 2-1.

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*Superscripts designate references.

Table 2-1

Comparison of Study Elements with Previous Wyle Reports

Study Factor	Wyle/DOT Report[1]	Wyle/EPA Report[2]	This Report
No. Air Carrier Airports	23	5	23 - Individual 92 - Airport Sample 180 - Census Sample
Final Year	1987	2000	1987
Base alternative for Future Years	6°/3°	"No abatement" baseline	"No abatement" baseline for 1975 All new aircraft FAR 36 in 1981 All aircraft FAR 36 in 1987
Abatement Alternatives			
• Source	• New technology aircraft in 1987 • SAM 3D/8D • REFAN 8D/SAM 3D	• New technology aircraft meet FAR 36 in 1987 and FAR 36-10 in 2000 • SAM 3D/8D • REFAN 8D • Demonstrate FAR 36-5, -10, -15, -20	• New technology aircraft meet FAR 36 in 1981 and 1987 • SAM 3D/8D • REFAN 8D (extrapolation only) • New technology aircraft at FAR 36-10 in 1987
• Operational	6°/3°	6°/3° approach, PCB, curfews, fleet size and mix change, flight track dispersion	6°/3° and 4° approach Power cutback Curfews
• Receiver	Not applicable	Not applicable	Relocation of residents Insulation noise reduction treatment Land acquisition
Demographic Data	Population density – 1970 Census	Not applicable	Population, housing, and land values-1970 Census and forecast
Air Carrier Fleet Forecast	Estimate to 1987 by detailed analysis of required and available air carrier transport capacity	Extrapolation beyond 1987 with gradually reducing rate of growth of required capacity, and unit productivity	Forecast of Wyle/DOT report revised to reflect energy crisis
Airport Operations Forecast	Estimate to 1987 based on detailed analysis of forecast passenger and cargo traffic at each airport and aircraft capacity by type	Extension of forecasts to year 2000 considering growth in aircraft capacity, and improved operating efficiency of airports	Same revision as above
General Aviation Airports	Not considered	Not considered	General aviation national model
Economic Effectiveness	Investment/operating cost model for SAM/REFAN	Not applicable	• Investment/operating cost model - Wyle/DOT report update • Other alternatives • Housing/land value
National Extrapolation	Not applicable	Extrapolation to nation based on evaluation of current and forecast profile of air carrier airports by number of operations	Extrapolation to nation - air carrier airports and general aviation airports by operation/area and population models
Noise Measure	NEF 30, 35, 40, 45	NEF 30, 35, and 40	L_{dn} 65, 70, 75, 80, 85 and Noise Unit (including ambient)

[1] DOT-TST-75-3
[2] EPA 550/9-73-021

2.2 Study Approach

Since this program was aimed toward cost-effectiveness evaluation of viable airport noise reduction alternatives at the national level, several basic requirements of the approach were apparent at the beginning. These included:

- The noise reduction alternatives selected were to be representative of actual or feasible concepts including aeronautical, operational, and receiver-oriented solutions.
- The national measure of noise impact required a more detailed analysis of noise impact at all the nation's airports than was available from previous studies.[1-5] Supporting data for estimates of impacted population also required more detailed documentation.
- Some means of modeling noise impacted areas and corresponding population was needed to provide reasonable estimates at the national level within the limits of the program resources.
- The national model dictated the need for some sort of sampling process to establish statistically average airports (AVports) representative of different levels of operational activity. These AVports were to be used to define the magnitude of the noise impacted areas for the nation.
- Future projections of AVport activity were to consider the potential change in air carrier activity due to the energy crisis.
- A sampling process was also envisioned to provide estimates of impacted population. Statistically average cities or towns (AVtowns) were therefore selected to allow estimates of impacted population near the AVports on the basis of average profiles of population density near airports. Three sizes of AVports and three corresponding sizes of AVtowns equivalent to areas around large, medium, and small airports were selected for the samples to represent the nation's air carrier airports.

- The statistical model AVports and AVtowns could be validated in part by comparison with the detailed results from the previous 23 airport study.[1] The latter established impacted population within airport noise contours using actual census data on population distribution within the specific contours near each of the 23 airports studied.
- The general lack of definitive data on operational mix of aircraft at general aviation airports dictated the need to construct a conservative estimate of the profile of general aviation airport operations by aircraft type. Four categories of general aviation airports (two with business jets and two without business jets) were used in this process.
- Noise impact analysis was to be conducted in terms of the L_{dn} noise metric and expressed in final form in terms of a weighted index of the impacted population. The impact index was to consider the difference between the total noise level, including non-aircraft ambient noise levels and specified criterion levels.[6, 7]

The basic elements of the study that evolved from these guidelines are:

- Selection of Airport Samples for Constructing AVports
- Definition of Operations at Each AVport for the 1972 Baseline
- Projection of Operations to Future Years
- Selection of Noise Reduction Alternatives
- Development of Population Models
- Evaluation of Demographic Variables Such as Size of Family Units and Value of Residential Land Around Airports
- Noise Impact Analysis for Each AVport-AVtown Combination and Extension to a National Estimate of all Noise Abatement Alternatives
- Evaluation of the Noise Impact Around General Aviation Airports
- Cost Analysis at the National Level of the Noise Abatement Alternatives

Each of these steps in the approach to this program will be considered in the text to follow. The final results are summarized in Section 4.

2.3 Air Carrier Airport Selection

There were approximately 514 airports in the U.S. in 1972 which offered air carrier service.[8] Of these airports, 301 have air traffic control (ATC) towers.[9] These 301 airports, however, represent 99 percent of the 183 million annual air carrier enplanements and 97 percent of the approximately 10 million annual operations in calendar year (CY) 1972.[1, 8]

It was assumed from the beginning of this program that the Wyle/DOT 23 Airport study[1] would be the starting point in determining the sample of airports to be utilized. The 23 airports in the Wyle/DOT study represented the largest U.S. continental airports on the basis of containing the majority of people residing within their noise impact boundaries. These 23 airports are listed in Table 2-2 along with their average daily traffic in 1972. From Chicago-Midway, with 114 operations per day, to Chicago-O'Hare, with 1592 operations per day in 1972, these 23 airports, therefore, provided a sample of all air carrier airports in the nation with more than 100 operations per day. A single average airport, called AVport I, was constructed from the 23 airport sample to represent all the air carrier airports in the nation with more than 100 operations. The method for constructing this AVport and scaling its noise impact to a national level will be explained later.

The 23 airports which comprise AVport I represent 45 percent of the operations at all air carrier airports in CY 1972. It was estimated, on the basis of earlier analyses,[2] that those airports with less than 10 jet operations per day would in all probability not present a significant noise problem and were therefore excluded from the study. This category represented about 2.2 percent of the operations at all air carrier airports. It was further concluded that the remaining 52 percent, i.e., airports with between 10 and 99 daily operations, could conveniently be divided into two categories - those falling between 10 and 39 daily operations in CY 1972 and those between 40 and 99 operations. Twenty-seven percent of all air carrier airports fell into the area between

Table 2-2

23 Airports from Wyle/DOT Study

No.	Airport	Code	CY 1972 Daily Operations
1	Atlanta - Hartsfield	(ATL)	1136
2	Boston - Logan	(BOS)	589
3	Buffalo	(BUF)	203
4	Chicago - Midway	(MDW)	114
5	Chicago - O'Hare	(ORD)	1592
6	Cleveland - Hopkins	(CLE)	361
7	Denver - Stapleton	(DEN)	522
8	Dulles - International	(IAD)	168
9	John F. Kennedy	(JFK)	673
10	La Guardia	(LGA)	796
11	Los Angeles - International	(LAX)	1018
12	Miami - International	(MIA)	658
13	Minneapolis - Wold Chamberlain	(MSP)	338
14	Newark	(EWR)	477
15	New Orleans - Moisant	(MSY)	300
16	Philadelphia - International	(PHL)	475
17	Phoenix - Sky Harbor	(PHX)	211
18	Portland - International	(PDX)	223
19	San Diego - Lindberg	(SAN)	208
20	San Francisco - International	(SFO)	780
21	Seattle - Tacoma	(SEA)	299
22	St. Louis - International	(STL)	502
23	Washington - National	(DCA)	600
	Total		12443

10 and 39 and AVport II was constructed from this category. The remaining category, with daily operations between 40 and 99 constituted 11 percent of the total airports and 13 percent of the total daily operations in 1972. A mid-range AVport (III) was constructed from this category. Figure 2-1 illustrates this distribution of the AVport categories and identifies the sample size for each category.

For AVport II, a sample of 30 airports was randomly chosen with the FAA "Airport Activity Statistics"[10] from the airports with annual operations falling between 3600 and 14,400 annual operations (~ 10 to 39 daily operations).

Table 2-3 identifies the AVport II airport sample along with their average annual operating levels.*

In order to demonstrate confidence in the range of airports falling between the AVport I and AVport II models, a Mid-Range Airport sample (AVport III) was derived, i.e., airports with 40 to 99 average daily scheduled operations. This sample was again selected from the FAA "Airport Activity Statistics" report, 1972.[10] **

Initially, all airports with operating levels between 40 to 99 average flights per day were identified. These were then divided into three categories: Category A = 40 to 59, Category B = 60 to 79, Category C = 80 to 99 operations per day. The airports in each of the three categories were equally distributed. From each of the three categories, a random sample of 9 or 10 was selected. A sample of 29 airports, representing 53 percent of all airports in the range between 40 to 99 operations per day, ultimately formed the basis for the mid-range (AVport III) model. Table 2-4 identifies the 29 airports used for this mid-range AVport along with their average daily operating levels.

Figure 2-2 illustrates the total distribution of all air carrier airports in 1972 by number of daily operations. For convenience, the latter have been broken down into ranges spaced geometrically and varying from one level to another by a constant ratio of 1.26 so that there are 10 equal steps in operations per day over a 10-to-1 range.

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*For further details on operating levels see Tables I-3 and I-4 in Appendix I.

**See Appendix I, Table I-5 for additional detail.

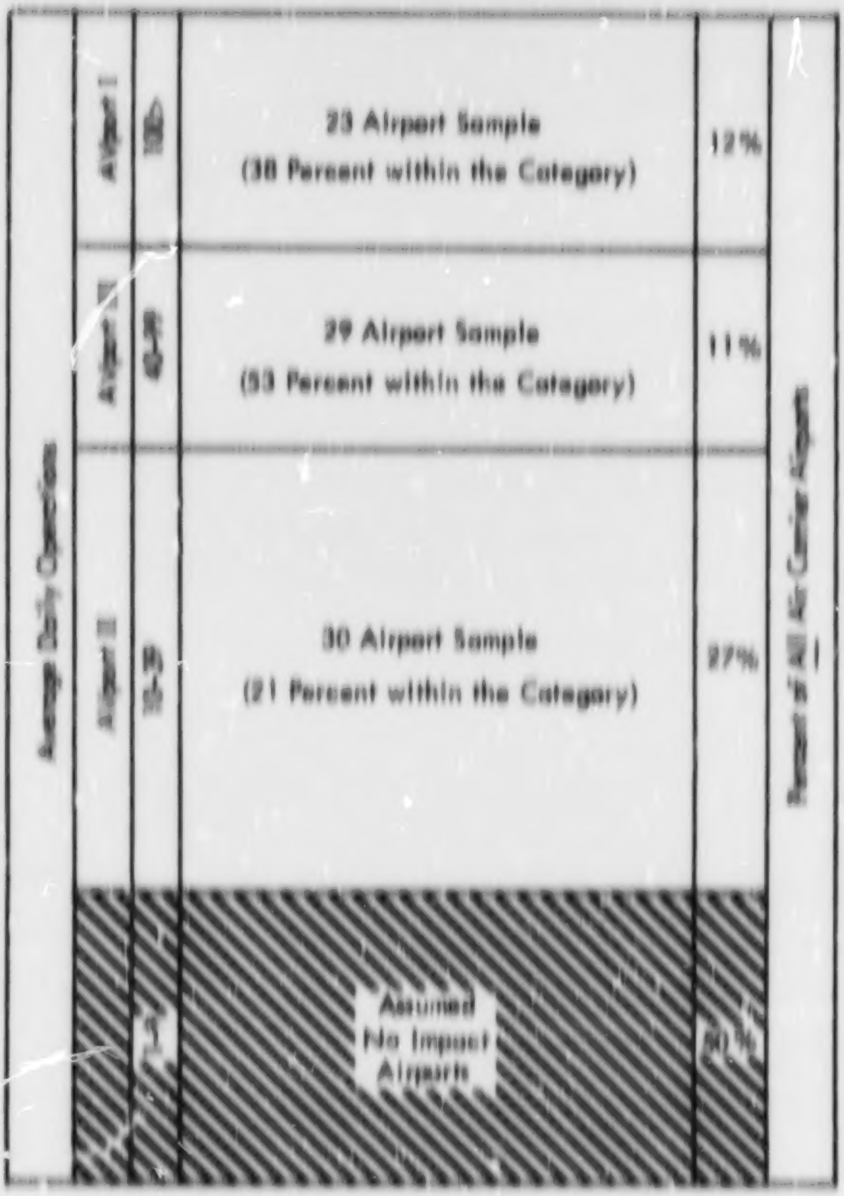

Figure 2-1. Percent of Airports by Operations for 514 Scheduled Air Carrier Airports - CY 1972[10]

Table 2-3

AVport II Sample

Airport	State	Average Annual Operations (000) 1977	1981	1987	Longest Runway Length Feet
Fort Smith	Arkansas	12.9	16	18	7,516
Bakersfield	California	5.4	7	8	6,708
Bradford	Pennsylvania	5.0	6	7	6,500
Santa Barbara	California	4.7	7	8	6,048
Pueblo	Colorado	5.6	7	8	10,497
Daytona Beach	Florida	11.9	16	18	7,499
Savannah	Georgia	12.0	15	17	9,000
Champaign/Urbana	Illinois	12.7	15	17	6,500
Decatur	Illinois	5.4	6	7	6,500
Fort Wayne	Indiana	9.7	15	17	8,367
Alexandria	Louisiana	8.4	9	10	5,999
Bangor	Maine	4.4	13	14	11,438
Flint (Bishop)	Michigan	8.9	10	11	7,850
Meridian	Mississippi	3.1	5	5	8,004
Manchester/Concord	New Hampshire	3.8	6	7	6,999
Jamestown	New York	4.3	5	4	5,300
Youngstown	Ohio	8.4	10	11	7,493
Lawton/Fort Sill	Oklahoma	6.6	5	5	8,600
Eugene	Oregon	7.4	11	13	6,204
Medford	Oregon	5.3	7	8	6,300
Wilmington	North Carolina	9.5	14	15	8,000
Scranton/Wilkes Barre	Pennsylvania	6.0	7	8	6,450
Rapid City	South Dakota	10.3	11	13	7,423
Abilene	Texas	5.0	6	7	7,199
Burlington	Vermont	9.3	10	11	7,807
Staunton	Virginia	4.6	6	7	6,002
Parkersburg/Marietta	West Virginia	6.6	7	8	5,100
Oshkosh/Appleton	Wisconsin	9.4	10	11	6,700
Cheyenne	Wyoming	5.7	10	11	9,199
Yakima	Washington	7.9	11	13	6,607
Total Average		7.5	9.0	10.0	7,024
*Percent Growth Factor		20%>	11%>		

*Derived from the "Airport Activity Statistics" and "Terminal Area Forecast" for the 30 airports.

Table 2-4

1972 Operations at Mid-Range Airports Used for AVport III

Airport	Average Daily Scheduled Operations			Longest Runway Length in Feet
	Cat. A 40 to 59	Cat. B 60 to 79	Cat. C 80 to 99	
Huntsville/Decatur, AL	50			8,000
Mobile, AL	56			6,800
Anchorage, AK		67		11,000
Tucson, AZ		77		12,000
Little Rock, AR		76		6,880
W. Palm Beach, FL			84	7,991
Lihue, HI	54			
Kahului, HI			97	
Springfield, IL	44			7,999
Cedar Rapids, IA	47			7,000
Des Moines, IA		77		9,000
Wichita, KS		72		5,000
Shreveport, LA			80	7,300
Grand Rapids, MI		65		7,600
Jackson/Vicksburg, MS			87	8,500
Billings, MT	52			8,000
Albany, NY			95	9,000
Fayetteville, NC	47			7,500
Greensboro/H.Pt., NC			88	8,201
Providence, RI		74		6,402
Charleston, SC	54			9,000
Columbia, SC		75		7,551
Sioux Falls, SD		70		8,000
Chattanooga, TN	50			7,400
Knoxville, TN			90	9,000
El Paso, TX			84	12,103
Lubbock, TX		67		8,500
Midland/Odessa, TX	50			5,810
Norfolk, VA			96	7,500
Average	49.4	70.6	88.2	8,063

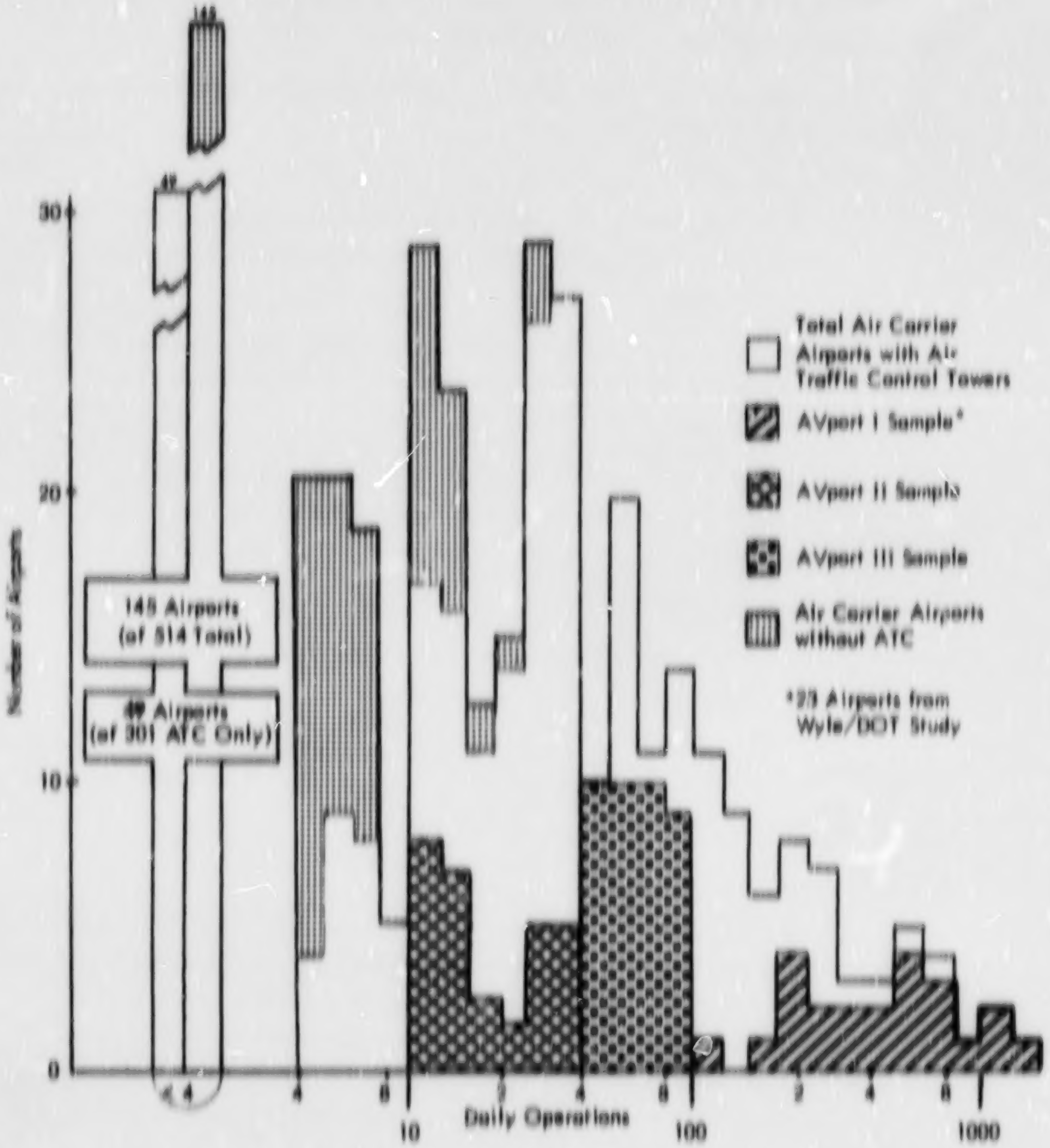

Figure 2-2. Profile of Number of Airports by Average Daily Operations at 514 U.S. Air Carrier Airports - CY 1972

Figure 2-2 also shows the distribution of the three AVport samples and identifies the air carrier airports with air traffic control (ATC) towers.

From each of these AVport samples, one hypothetical single-runway airport was constructed in the following way.

1. Based on the actual 23 airport data, an average runway utilization (in percent) for takeoff and landing in each direction of a single-runway AVport was determined. This runway utilization mix was applied to all three AVports.

2. For each AVport sample, the actual type of aircraft and trip lengths were determined to allow noise contours to be constructed for each single-runway model.

3. Day-night split, required for computation of the average day-night sound level, was computed for each AVport on the basis of the average actual day-night split for all airports in each AVport sample.

Further details for each AVport will be covered later under Section 2.6.

Airports not included in this study include heliports, seaplane bases, and military air bases. Although exact figures are not available, it is believed that the impacted population around these facilities, most of which have very low operational traffic, is a small fraction of that considered in this report.

2.4 Projected Aviation Activity

2.4.1 Selected Future Years

The selection of future years for testing the implementation and subsequent cost analysis of the various noise reduction alternatives was partly arbitrary and partly based on an objective of being consistent with the selection made in the Wyle/DOT study.[1] These assumptions pertain primarily to the projected implementation schedule of the three major aeronautical noise reduction alternatives, i.e., completion of SAM before 1981, REFAN by 1981, and the influence of a modified FAR 36 noise certification rule such as FAR 36-10 after 1981. The span of 15 years from the initial starting year of 1972 appeared to be a reasonable time frame to demonstrate the effectiveness of noise reduction alternatives. Thus, 1972 was selected as the baseline year, 1987 as the end point and 1981 to verify trends.

For these years, it was necessary to predict the level and type of aircraft operating at each of the AVports and to estimate the change in population around the airport. For the former projection, the forecast of air carrier activity for the years 1981 and 1987 from the Wyle/DOT report[1] was modified slightly as outlined below, to reflect the anticipated direction of changes in aviation growth due to the current energy crisis. For the population projections, the 1970 Series D census projections through the year 1985 were used to forecast a uniform increase in population density for each study year relative to the values in 1972.

A rough projection of growth in general aviation operations was also made for the analysis of general aviation airport noise impact. This is treated in Appendix H.

2.4.2 Forecast of Future Air Carrier Activity

The fleet mix and operations forecast developed in the Wyle/DOT study[1] were initially agreed upon as adequate for the purpose of this study and applicable for the construction of AVport I. It soon became evident, however, that since the original Wyle/DOT study, an energy crisis had occurred and that changes in the current and projected fleet composition have become apparent. Not only this, but for the first time in air transportation history, the level of operations was down and new reduced air transportation growth trends were being felt and projected along all fronts of the industry. For this study, a simplified revision to the earlier projections in Reference 1 was made to reflect the influence of the energy crisis indicated by revised projections by industry (Air Transport Association)[11] and the FAA.[12]

Since the advent of the energy crisis, both FAA and ATA have revised their projections of total aircraft and operations of the U.S. Air Carrier Fleet to reflect a decrease in the growth rate of aviation in the next 10 years. To provide a rationale for considering the potential effect of these revisions on the Wyle/DOT 23 airport model (which projects traffic to 1987 for each airport by aircraft type), the following analysis was carried out.

2.4.2.1 Summary of Revised Forecast

a. The fleet mix for the years 1978 and 1981 was revised to show approximately the same percentage distribution of 2-, 3-, and 4-engine narrow body, and 3- and 4-engine wide body aircraft as projected by ATA. This resulted in decreasing the total number of aircraft in the fleet by about 4 percent for 1978 and by about 10 percent for 1981.

b. The fleet mix for the year 1987 (beyond the ATA projections) was extrapolated by continuing the trends from the earlier years, resulting in:

- A significant decrease in the growth rate of 3-engine wide body aircraft through 1987 and 4-engine wide body aircraft for 1987 only.
- A compensating slowdown in retirement of 3-engine narrow body aircraft (727) and a predicted increase in the number of new such aircraft.

c. The total number of aircraft in the 1987 fleet was adjusted downward by 30 percent to reflect the indicated slowdown in air carrier growth and the estimated reduction in enplaned passengers as recently forecast by FAA.[12]*

Based on these changes in the total number of aircraft of each type in the fleet and the general stability of the operational productivity factors for the air carrier fleet (i.e., the average operations per year for each aircraft type), it was possible to estimate the changes in the total number of operations per year by aircraft type. This change in the total number of operations was then applied directly as a correction factor to the number of operations of the corresponding aircraft types at each airport.

The procedure is obviously approximate since it does not consider the detailed strategies that individual airlines may employ in response to higher fuel costs modifying the type of service or aircraft employed in particular city-pair air carrier operations.

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*For further detail, see Tables I-1 and I-2 in Appendix I.

This study, however, emphasizes trends in aggregate effectiveness and costs of aircraft/airport noise reduction countermeasures at the national level. For these purposes, the estimating procedure appeared reasonable and should adequately reflect the general trend in air carrier operations resulting from the energy crisis.

2.4.2.2 Background for Revisions to Projected Air Carrier Operations

a. Projections of Passenger Enplanements and Operations at 23 Airports

The FAA "Terminal Area Forecast" reports currently available for the period 1976-1986 (issued September 1974) and the "Aviation Forecasts Fiscal Years 1975-1986" provide a reasonable basis for estimating total passenger enplanements from all aircraft in the U.S. fleet and total operations of air carrier aircraft at any one airport. However, these reports do not provide any breakdown by aircraft type at each airport.

Table 2-5 compares these recent FAA projections of Total Passenger Enplanements and Operations and those of Wyle/Speas for the 23 airports in the Wyle/DOT 23 Airport report.

Extrapolating the FAA projected operations from 1986 to 1987 shows for 1987 a total 6,747,000 for the 23 airports, compared to 6,385,000 operations projected in the Wyle/DOT report. The difference is only 5.4 percent (0.2 dB when converted to L_{dn} values). On the basis of this small difference in total operations, one could potentially neglect any changes in forecasts of operations. Further examination was warranted, however. This projection of passenger enplanements and operations was therefore cross-checked against projections of fleet size.

b. Projections of Air Carrier Fleet Size

Figure 2-3 compares the various projections of the total aircraft in the U.S. air carrier fleet by:

- Wyle/Speas forecast in 1972 (and current Wyle revision - 1975);
- FAA before and after energy crisis (1973, 1974);

Table 2-5

Comparison of FAA and Wylie/Speas Forecasts of Annual Enplaned Passengers (PAX) and Operations (OPS) in Thousands at 23 Airports

No.	Airport	*FAA Forecast (Fiscal Year)						Wylie/Speas Forecast**	
		1976		1981		1986		1982	1987
		PAX	OPS	PAX	OPS	PAX	OPS	OPS	OPS
1	Atlanta – Hartsfield	1129	422	1679	546	2077	612	538	648
2	Boston – Logan	575	199	784	257	967	288	247	299
3	Buffalo	107	74	159	95	207	87	90	93
4	Chicago – Midway	390	25	260	132	432	145	144	172
5	Chicago – O'Hare	1240	573	2098	657	2490	697	615	624
6	Cleveland – Hopkins	298	127	425	144	539	186	149	159
7	Denver – Stapleton	467	196	749	252	933	284	259	251
8	Dallas – International	124	58	196	55	201	53	111	147
9	John F. Kennedy – International	1029	286	1515	295	1676	444	248	265
10	La Guardia	725	305	1045	342	1267	384	235	259
11	Los Angeles – International	1197	351	1697	440	1908	442	406	471
12	Miami – International	526	223	776	288	971	326	297	340
13	Minneapolis – Wold Chamberlain	257	131	429	149	522	190	153	172
14	Newark	246	150	382	194	444	217	241	264
15	New Orleans – Moisant	216	142	288	131	407	148	155	210
16	Philadelphia – International	299	165	542	207	673	222	224	257
17	Phoenix – Sky Harbor	168	84	253	108	345	121	112	149
18	Portland – International	172	78	231	103	256	113	119	163
19	San Diego – Lindbergh	178	73	179	94	232	125	107	142
20	San Francisco – International	748	275	1261	255	1546	299	274	480
21	Seattle – Tacoma	249	159	322	141	423	156	146	180
22	St. Louis – International	328	168	587	233	708	288	257	318
23	Washington – National	538	214	628	232	924	254	228	230
TOTAL			4562		5344		6128	5601	6585

*Terminal Area Forecast, 1976-1986, FAA September 1976[3]

**Reference 1

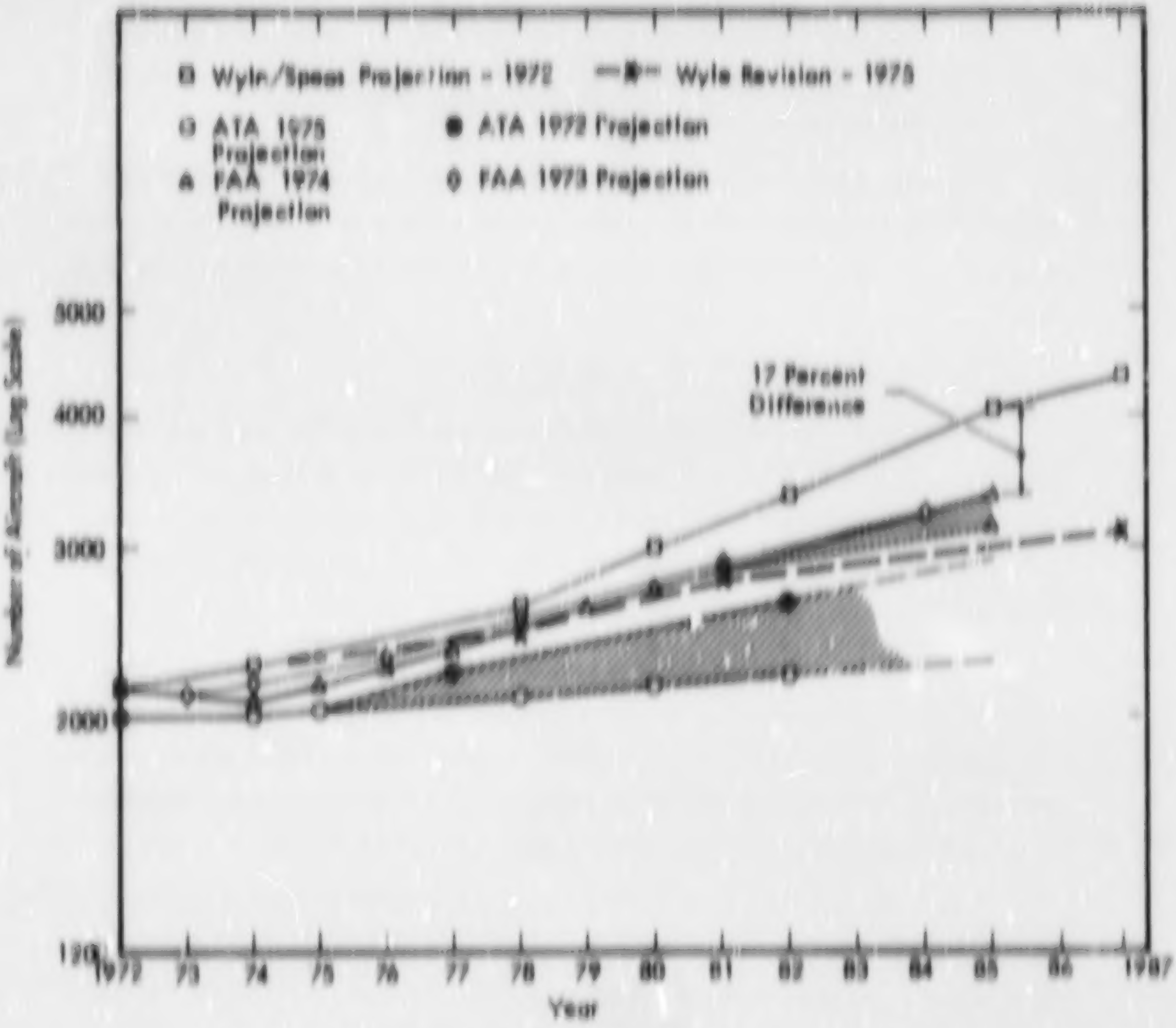

Figure 2-3. Comparison of Jet Aircraft Fleet Forecasts

Wyle Includes:	ATA Includes:	FAA Includes:
• Scheduled • Nonscheduled • International Cargo	• Scheduled U.S. Carrier Only • ATA Member Airlines Only	• Total Air Carrier Jet Fleet

- ATA before and after energy crisis (1972, 1975). Note: The ATA fleet projections are for ATA-member companies which operated 87 percent of the total U.S. fleet in 1974.

Clearly, Figure 2-3 shows major differences in the various projections of fleet size which are inconsistent with the small difference noted in Table 2-5 in the operations data for the 23 airports. This difference leads to consideration of projections of the fleet mix.

c. Projection of U.S. Air Carrier Fleet Mix

Figure 2-4 compares the Wyle/Speas projections of total fleet mix[1] with ATA projections made in 1972 and 1975 (before and after the energy crisis became significant). It is immediately apparent that the Wyle/Speas projections of the growth rate in wide body aircraft is much greater than the ATA projections – especially the ATA projection made in 1975.

Some means is desirable, therefore, to allow all three projections (Wyle/Speas, ATA, and FAA) to be compared. On the basis of: (a) the data on projected mix of aircraft and annual operations by aircraft type in the Wyle/DOT report, (b) seating capacity and load factor data from previous Wyle studies, and (c) FAA total passenger enplanement predictions, computed trends in annual enplaned passengers could be compared.

There was essentially no difference between the estimated passenger enplanements based on the original (1972) Wyle/Speas aircraft fleet projection and the (1974) FAA projection of passenger enplanements up to 1978. However, after 1978, the FAA projections indicate a substantial decrease in the growth rate.

Before any attempt was made to estimate a possible change in the Wyle/Speas 1972 projections, the FAA and ATA fleet projections which straddle the energy crisis considerations were reexamined. Table 2-6 compares relevant data on the fleet size, mix, and operations for the year 1981 based on these FAA and ATA projections. The

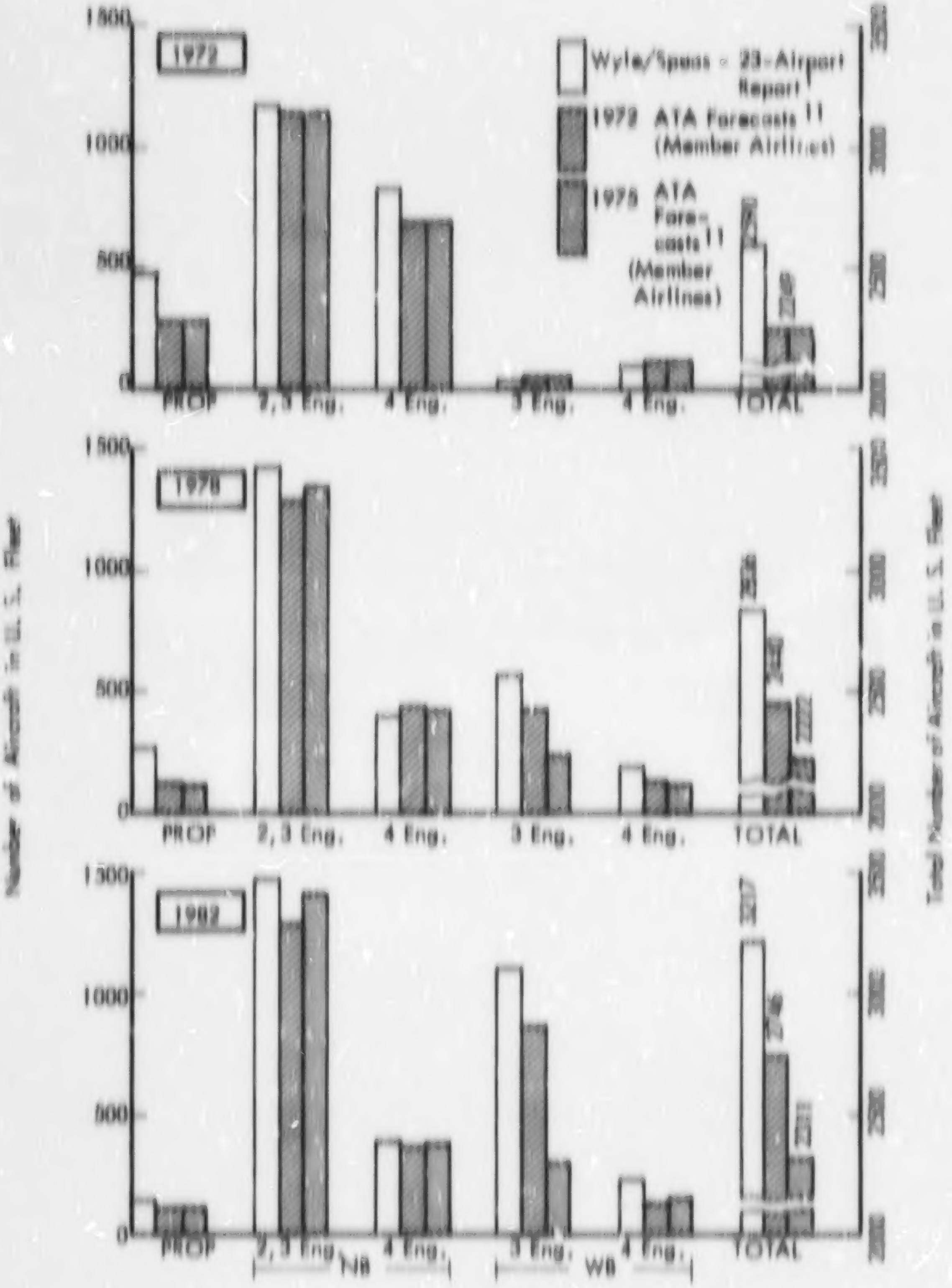

Figure 2-4. Comparisons of Projected Fleet Mix

Table 2-6

Comparison of FAA and ATA Fleet Projections for 1981 Made Before and After Energy Crisis

Type of Aircraft		FAA			ATA		
		1973[(1)]	1974[(2)]	Δ%	1972[(1)]	1975[(2)]	Δ%
Narrow Body	2-Engine				582	484	-17
	3-Engine				706	915	+29
	4-Engine				372	369	-1
Wide Body 2-,	3-Engine				728	273	-62
	4-Engine				132	136	+3
Narrow Body, Wide Body	2-Engine	993	749	-25	582	484	-17
	3-Engine	1305	1440	+10	1436	1184	-17
	4-Engine	582	644	+11	504	505	~0
Propeller		188	243	+29	109	106	-3
Total Aircraft		3068	3076	~0	2631	2283	-13
Total Ops × 10^6		12.1	12.3	+2			
Enplaned Passengers × 10^6		386	313	-19			

(1) Year estimate made before energy crisis.

(2) Year estimate made after energy crisis.

"Δ" columns show the percentage change in the projections which presumably reflect the effect of higher fuel costs; an examination of which shows new trends emerging in addition to what has already been shown.

- The FAA fleet mix projections indicate a substantial decrease (25 percent) in the number of 2-engine (narrow body) aircraft between the 1973 and 1974 projections and a 20 percent decrease in the passenger enplanements.
- The two ATA projections of fleet mix are characterized by a general decrease (13 percent) in total number of aircraft in contrast to essentially no change in the total fleet size indicated by FAA; however, ATA shows a marked increase (+29 percent) in the number of 3-engine narrow body aircraft and the sharp drop (-62 percent) in the number of 2-, 3-engine wide body aircraft already noted. The result is a net decrease of 17 percent in both types of 3-engine aircraft in contrast to the 10 percent increase predicted by FAA for 3-engine jets.
- The change shown in Table 2-6 in FAA projections of enplaned passengers is apparently due to a projected decrease in load factors since the only aircraft type whose total number decreases is the 2-engine jet which is estimated to have the lowest average enplaned passengers per aircraft. Thus, trends in enplaned passengers predicted by FAA are not necessarily a reliable indicator of trends in aircraft operations.

From this rather confusing array of trends and, to some extent, conflicting data, one can conclude that FAA considerations of the energy crisis are dominated by a decrease in passenger enplanements without any substantial change in total aircraft in the fleet (as of 1981). The changes in fleet mix consist of small increases (~ 10 percent) in 3- and 4-engine aircraft and a substantial decrease (25 percent) in 2-engine aircraft. Furthermore, ATA considerations of higher fuel costs are dominated by a marked decrease in 3-engine wide body aircraft in the fleet and a small (13 percent) decrease in the total fleet.

d. AVport I Forecasts

Based on these observations, two alternative actions relative to revising fleet forecasts were considered for application to the forecast operations for AVport I.

- Make no changes in the 1981 or 1987 mix for operations in order to retain integrity of all the previous results embodied in the Wyle/DOT 23 Airport report.
- Change the operations at all airports of the 3-engine narrow body and wide body aircraft types in direct proportion to an average change in the total number of the aircraft in the fleet. These changes in the fleet mix will show a decrease in total passenger enplanement consistent with the recent FAA predicted trends and a decrease in the total number of aircraft consistent with the recent ATA predictions.

While it was anticipated that significant changes in airport noise impact would not result from aviation activity changes caused by the energy crisis, nevertheless, it was desirable to make some reasonable provision for the expected changes in fleet mix in order that future noise reduction alternatives can be more accurately assessed. Thus, the second alternative above was adopted for execution of this study.

The net effect of the resulting change in the forecast fleet is summarized in Table 2-7. This shows the number of aircraft of each general type in the fleet for the years 1978, 1981, and 1987. The estimated number of annual passenger enplanements for each year is also shown. The passenger enplanements were estimated on the basis of estimated passenger enplanements per operation for each aircraft type. The fleet numbers which have been revised are underlined. The last column for each of the years shows the percentage of operations by aircraft type for the revised mix relative to the number of operations forecast in the Wyle/DOT 23 Airport report.[1] These percentages were applied uniformly to all operations at the 23 airports to account, approximately, for the effect of the fuel costs on air carrier operations for the future years for AVport I. The revised forecasts for total jet aircraft in the fleet from Table 2-7 were also plotted earlier in Figure 2-3 for comparison with the other forecasts.

Table 2–7

Comparisons of Projections for Air Carrier Fleet Before (1972) and After (1975) Energy Crisis

Projection For ⟶	1978			1981			1987		
Year Made[1] ⟶	1972	1975	Δ%[4]	1972	1975	Δ%[4]	1972	1975	Δ%[4]
Type of Aircraft									
2-Engine Narrow Body	576	576	100	596	596	100	492	492	100
3-Engine	853	982	116	893	1036	116	601	775	129
4-Engine	398	398	100	346	346	100	295	295	100
2-Engine Wide Body	20	307	55	140	470	51	445	951[3]	42
3-Engine	534			782			1470		
4-Engine	225	225	100	310	310	100	660	502	76
2-Engine New Technology							350		
Propeller	240	240	100	150	150	100	78	78	100
TOTAL	2846	2728	96	3217	2908	90	4391	3093	70
CPS x 10^6 – Nation	10.58	10.91	103	11.60	11.44	98.6	14.32	11.09[2]	77.4
Enplanement Passengers x 10^6 [2]	259.3	239.5	92.4	321.1	273.8	85.3	501.8	322.04	64.2

[1] Later projections intended to reflect higher fuel costs.

[2] Computed from estimated average passenger enplanements per operation by aircraft type.

[3] Includes new technology (2-engine) aircraft.

[4] Projection made in 1975 relative to projection made in 1972.

e. AVport II and Mid-Range Forecasts

The FAA Terminal Area Forecast, 1976-1986[9] was used as a means of projecting the growth of operations for the years 1981 and 1987 for those smaller airports identified in Tables 2-3 and 2-4. This forecast had already been adjusted by FAA to reflect the effect of higher fuel costs. While both the FAA and Wyle revisions to future fleet forecasts reflect higher fuel costs by showing a slowdown in air carrier growth, there are differences in the detail of revised fleet mix. However, these second order differences were not considered significant for the purposes of this study. The distribution of aircraft types was obtained from the 1972 "Airport Activity Statistics"[10] and "Official Airline Guide."[13] For the purpose of future forecast, it was assumed that aircraft such as the B-727-100 and BAC-111-200 series would be phased out by 1981 and replaced by B-727-200 and B-737-200 series.

2.5 Noise Abatement Alternative Selection

Noise abatement alternatives were selected to provide supportive data for EPA's rulemaking proposal activity for the control of aircraft and airport noise.

Consideration was given to those alternatives which hold the greatest promise for noise reduction, both individually and in combination with other alternatives. Three basic categories of noise abatement were tested to provide insight into their effectiveness in terms of area/population impact reduction. These categories are source noise modification, operational modifications, and receiver/land use modification.

Most of the operational alternatives were assumed to be "no-cost" alternatives or at least to have no easily identifiable cost factors. The cost burdens were often so diffuse that they could not be simply assigned to the airport, the airline, the aircraft industry or the public sectors. The benefits, likewise, were often intangible.

Table 2-8 shows a detailed comparison between the alternatives used in this study and those used in the earlier Wyle/DOT[1] and Wyle/EPA[2] studies. Each of the alternatives used in this study is briefly defined in this section.

Table 2-8

Comparison of Noise Abatement Alternatives for Current and Previous Studies

Current Study	Wyle/EPA Study[2]	Wyle/DOT Study[1]
Source Modification	**Source Modification**	**Source Modification**
Baseline 1972 Baseline 1981 (new aircraft meet FAR 36) 1981 SAM 8D and 3D 1981 REFAN 8D/SAM 3D (extrapolation only) 1981 Combination 6°/3°, PCB and SAM Baseline 1987 (new aircraft meet FAR 36) 1987 SAM 8D and 3D 1987 REFAN 8D/SAM 3D (extrapolation only) 1987 FAR 36-10 (only for new aircraft) 1987 Combination 6°/3°, PCB, SAM, FAR 36-10	Baseline 1972 Baseline 1987 (new aircraft meet FAR 36) 1987 SAM 1987 SAM, 6°/3°, and PCB 1987 REFAN 8D, SAM 3D, 6°/3°, and PCB 1987 REFAN 727-200, DC-9, and SAM 3D, 727-100, 737-100, 6°/3°, and PCB 1987 FAR 36-5, -10 Baseline 2000 (new aircraft meet FAR 36) 2000 SAM 2000 SAM, 6°/3°, and PCB 2000 REFAN 8D, SAM 3D, 6°/3°, and PCB 2000 REFAN 727-200, DC-9, and SAM 3D, 727-100, 737, 6°/3°, and PCB 2000 FAR 36-5, -10, -15, -20	Baseline 1972 1976 6°/3°, SAM 3D/8D 1981 6°/3°, SAM 3D, REFAN 8D 1987 6°/3°, SAM 3D/8D 1987 6°/3°, SAM 3D/REFAN 8D
Operational Modification	**Operational Modification**	**Operational Modification**
1981 6°/3° Approach 1981 PCB 1981 4° Approach 1981 Curfew - no night flights 1981 Curfew - night rescheduled to day 1987 6°/3° 1987 PCB 1987 4° 1987 Curfew - no night flights 1987 Curfew - night rescheduled to day	1987 6°/3° 1987 6°/3° and PCB 1987 Change in Fleet Size 1987 Change in Fleet Composition 1987 Night Curfews 2000 6°/3° 2000 6°/3° and PCB	1976 6°/3° Approach 1981 6°/3° Approach 1987 6°/3° Approach
Receiver Modification	**Receiver Modification**	**Receiver Modification**
1972, 1981, and 1987 Land Acquisition and Writeoff Residential Relocation Noise Reduction Treatment	None	None

For this study, no attempt has been made to evaluate the cost and effectiveness of optimum combinations of source, operational and receiver modifications. This is left for subsequent evaluation of optimum scenarios and financing schemes.

2.5.1 Source Modification

a. Baseline 1972, 1981, and 1987

The noise characteristics of the baseline aircraft were defined from currently available industry data on A-weighted noise levels[14-19] augmented by Wyle analysis to convert to time-integrated Noise Exposure Level (L_{NE}). This latter process is covered in more detail in Section 2.6.2. The baseline aircraft also utilized an ATA takeoff procedure and a 3° approach profile simulating an ATA-recommended flap management procedure. See Section 2.5.2 for additional details on these baseline operating procedures.

For 1981 and 1987, new production aircraft were assumed to have noise curves equivalent to those of comparable SAM retrofitted aircraft which meet FAR 36. These new production aircraft constituted a small percentage of the 1981 and 1987 baseline fleets.

b. SAM 8D and 3D

For this alternative, the same quiet nacelle or sound abatement material (SAM) treatment for current technology narrow body aircraft, analysed in Reference 1, was applied to all JT3D- and JT8D-powered aircraft consisting of DC-8, B707 (for JT3D engines) and B737, B727, and DC-9 models (for JT8D engines). The A-weighted noise levels versus slant range characteristics for these aircraft were based on industry data[14-19] augmented by Wyle analysis to correct to time-integrated Noise Exposure Level.

c. REFAN 8D/SAM 3D

This condition was evaluated by applying engine REFAN modifications, also evaluated in Reference 1, to current technology JT8D-powered narrow body aircraft and applying the quiet nacelle treatment to all JT3D aircraft. This alternative, however, was not tested directly in this study but was extrapolated from data in the previous Wyle/DOT and Wyle/EPA reports.[1, 2] The extrapolation consisted of estimating the change in impacted areas for the nation on the basis of the relative change observed in the previous reports when this option was applied.

d. FAR 36-10

Up to this point, the noise reduction alternatives considered have consisted of available operational procedures or aeronautical system changes currently being developed. In order to examine the potential effectiveness of further noise reduction, a FAR 36 – 10 dB alternative was explored. This study did not attempt to determine the feasibility or practicability of achieving this reduction in aircraft noise levels, although reduction in FAR 36 levels are under study by federal agencies. Rather, the objective was to develop a better perspective of the relative noise reduction value of this alternative if, in fact, it were to become available in future years.

The basic approach followed consisted of uniformly reducing the A-weighted noise level characteristics of each type of aircraft by the same amount necessary for corresponding revised EPNL* values to just conform to a FAR 36-10 certification level at the noisiest certification measurement point for each aircraft. This was either the takeoff (3.5 n mi) or landing (1.0 n mi) point in all cases. Table 2-9 defines the approximate noise level, in terms of EPNL values relative to FAR 36 limits, for each type of aircraft and the two noisiest FAR 36 measurement positions. The relative EPNL levels are specified for narrow body aircraft in a SAM configuration and for wide body aircraft in the current baseline configuration. It can be seen from the data in Table 2-9 that the resulting noise levels for narrow body aircraft with SAM or wide body aircraft would either equal or fall significantly below FAR 36 criteria for most aircraft types. However, the same aircraft would not meet a FAR 36-10 alternative without further noise reduction. Thus, referring to the column under Takeoff for the 727 (with SAM), the relative EPNL level is 1 dB below existing FAR 36 levels so that an additional 9 dB decrease in level would be required to achieve a FAR 36-10 limit. This -9 dB correction was applied (uniformly at all distances and at all thrust levels) to the existing SAM A-weighted noise versus slant range curves to achieve the desired FAR 36-10 alternative. This simple correction process to achieve a specified level below current FAR 36 requirements resulted, as expected, in hypothetical aircraft noise

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*EPNL, Effective Perceived Noise Level, is the noise metric used for FAR Part 36.[25]

Table 2-9

EPNL Values Relative to Current FAR 36 Limits, dB(1)
(All Values Calculated from Noise and Profile Curves in References 14-19)(2)

Aircraft	Configuration	FAR 36 Position	
		Approach	Takeoff
DC-9	SAM	+2 dB	+3 dB
737		-5 dB	-2 dB
727		-2 dB	-1 dB
707/DC-8		-4 dB	-1 dB
2-Engine Wide Body	Baseline	-5 dB	-9 dB
DC-10		-5 dB	-7 dB
L-1011		-5 dB	-7 dB
747		-2 dB	-1 dB

(1) Plus (+) indicates EPNL is higher than FAR 36 limits, while minus (-) indicates EPNL is below FAR 36 limits.

(2) These relative FAR 36 levels were computed on the basis of the following assumptions:

- 59°F day (not adjusted to 77° F FAR 36 standard day).
- On takeoff, FAR 36 power cutback applied for current narrow body aircraft at 3.5 n mi point.
- Approach flap settings correspond to the values used in Reference 1 which were based on typical industry data.
- Approach landing weight was assumed to be maximum allowable.

The relative FAR 36 levels in this table do not necessarily reflect the latest FAR 36 noise level data. Recent FAA data show that all SAM retrofitted aircraft are expected to comply with FAR 36[20] as, in fact, they are required to do by law.[21]

characteristics which just met the desired limit at one of the three certification points but usually fell well below the allowed limits at the other points.

The resulting changes in noise level and the aircraft to which they were applied to achieve the FAR 36-10 aircraft noise level alternative are summarized in Table 2-10.

Table 2-10

Noise Level Corrections Applied Uniformly to Noise Curves to Achieve FAR 36-10 Levels, dB

Aircraft	Correction, dB
2-Engine Narrow Body	SAM-13
3-Engine Narrow Body	SAM-9
4-Engine Narrow Body	SAM-9
2-Engine Wide Body	-5
3-Engine Wide Body	-5
4-Engine Wide Body	-9

This alternative was applied to the 1987 time period only, and then only to those new production aircraft which were assumed to go into service during the 1981-1987 time frame. This was essentially represented by the number of additional daily operations for each aircraft type from 1981 to 1987. It will be shown later that due to the relatively small number of aircraft operations to which this alternative was applied in 1987, the net decrease in noise impact was relatively small. A much greater impact reduction was shown in the previous Wyle/EPA report for the year 2000 when it was assumed that all air carrier aircraft would meet this alternative by this latter date.[2]

2.5.2 Operational Modifications

2.5.2.1 Approach Profile Modifications

a. Baseline Approach Profile

The baseline approach profile procedure is a simulation of ATA 3° approach procedures including the ATA-recommended flap management (noise abatement) procedure.[1] The latter is spelled out, as follows, from the ATA Operations Policy Manual.

> "NOISE ABATEMENT APPROACH AND LANDING PROCEDURES 6-15-74
>
> Policy:
>
> The recommended steps for noise abatement approach for use at all airports with all types of approaches (ILS, VOR, Visual, etc.), both IFR and VFR are as follows:
>
> 1. Approach the airport area at as high an altitude as possible (at airport with control towers, "Keep Them High" assists here);
> 2. Remain in a clean configuration for as long as possible;
> 3. Proceed in-bound from the final approach fix, or a similar distance for a visual approach, with flaps set at one "notch" less than final landing flaps planned for the particular landing;
> 4. Extend final landing flaps at a point on final approach at which the aircraft is 1000 feet above field elevation, equipment performance permitting;
> 5. Use the lowest allowable landing flap setting which is permissible for the particular landing, e.g., on B-727 use 30 degrees flap setting for landing, whenever the specific runway and runway conditions will allow.
>
> Note: To maximize noise abatement benefits, it is further recommended that initiation of each successive flap extension be made at a speed near the minimum speed for that particular configuration. Step 4 above contemplates final approach stabilization at not less than 500 feet above field elevation."

The actual approach profile utilized is illustrated in Figure 2-5. Table 2-11 lists the flap settings and landing weight utilized for establishing thrust settings for these profiles. The actual thrust settings were determined from the estimated flight characteristics for the aircraft.

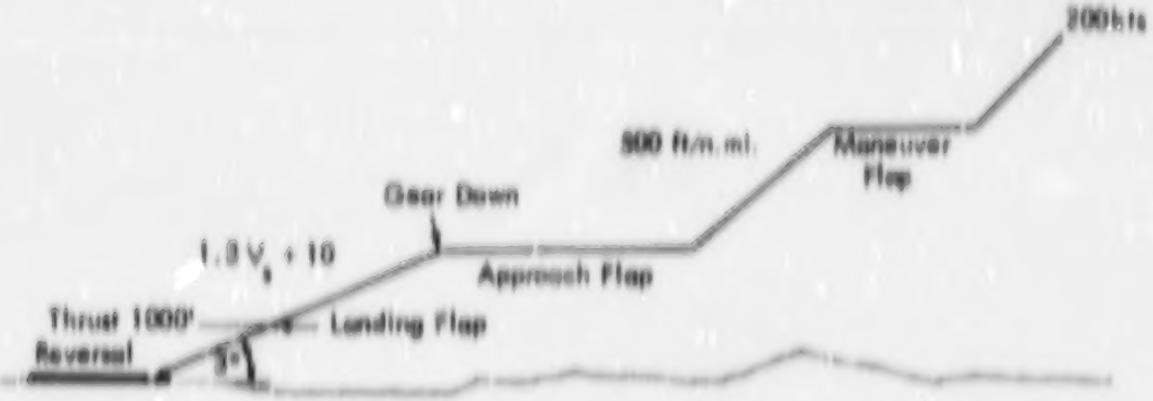

Figure 2-5. Typical 3° Approach Profile

Table 2-11

Aircraft Configuration During Baseline 3 Degree Approach

Aircraft	Arrival Flaps,[*] Degrees	Landing Weight, lbs
DC-9-15	15-20-50	80,000
DC-9-32	15-20-50	75,000
DC-8-33	30-35-50	180,000
DC-8-61	25-35-50	197,800
DC-10-10	5-18-35	300,000
737-200	5-25-40	88,000
727-100	5-25-40	138,200
727-200	5-15-30	150,200
707-320B/C	14-30-40	190,000
747-100/-200B	10-25-30	500,000

[*] Manuever, Approach and Landing Flap Angle.

Figure 2-6 shows the computed change in the drag (D) to lift (L) ratio for a 727-200 aircraft on approach for several descent angles and flap settings. The expected increase in D/L with increasing flap setting angle is clearly evident in this figure. Based on this type of performance data and a simple aerodynamic performance model expressed by

$$\frac{T}{W} = \frac{D}{L} \pm \gamma$$

where

T/W = thrust to weight ratio
D/L = drag to lift ratio
γ = flight path gradient (+ for takeoff and negative for landing)

it was possible to estimate the approach thrust and the corresponding curve of noise level versus slant range for any desired flap setting and descent angle.

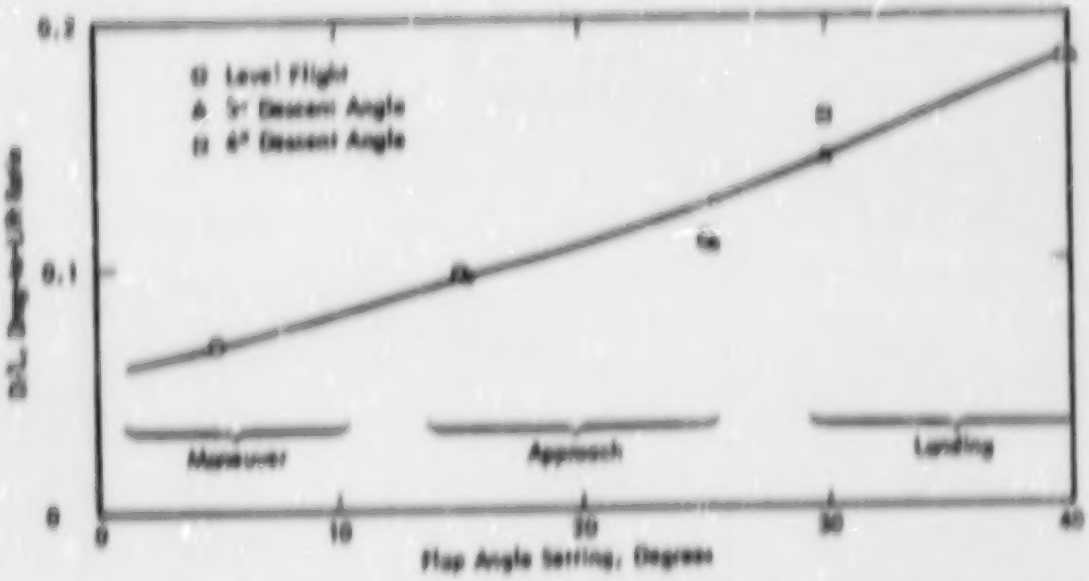

Figure 2-6. Computed Drag-to-Lift Ratio Based on Flight Performance Data for 727-100 Aircraft (see Appendix B of Reference 1)

b. Two-Segment (6°/3°) Approach Profile

For the years 1981 and 1987, a two-segment (6°/3°) glide slope noise abatement approach was investigated as one of the operational alternatives. This procedure involves intercepting the 6° portion of the glide slope at an altitude of 3000 feet or above, then descending at a 6° angle until reaching an altitude of 690 feet where the transition to the 3° portion begins. The aircraft is established on the 3° glide slope at or above an altitude of 500 feet. The 3° descent angle is maintained until touchdown. The procedure is approximated by straight line segments for the L_{dn} computer program model as shown graphically in Figure 2-7.

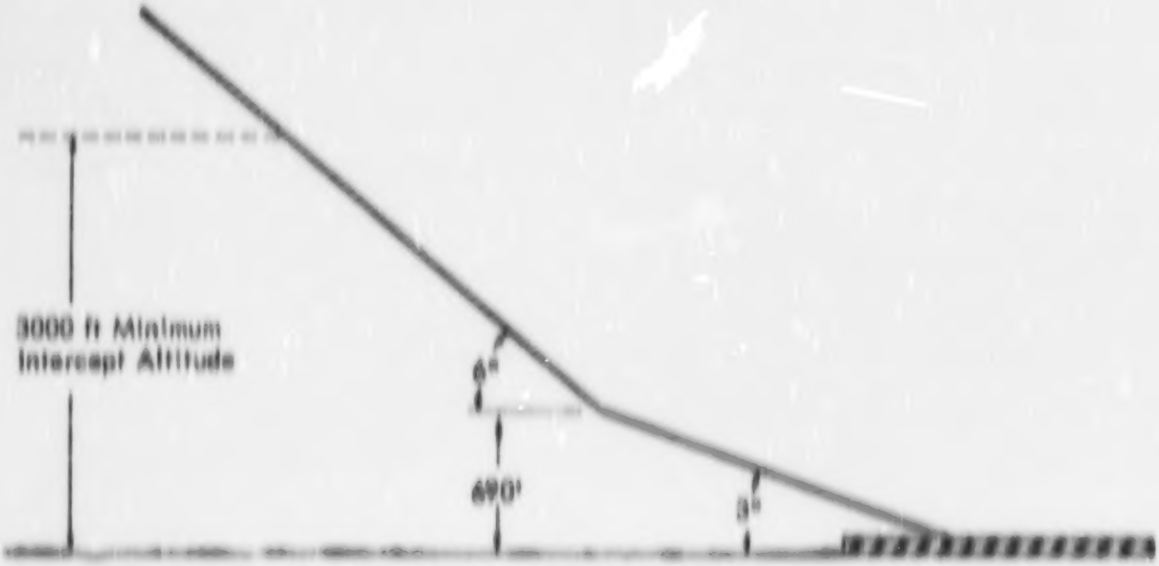

Figure 2-7. Two-Segment (6°/3°) Approach Profile

Normal aircraft approach intercepts for a 3° glide slope occur at 2500 to 3500 feet altitude, depending on the ground track. For the 6°/3° glide slope procedure, the 6° portion of the approach is initiated at a minimum of 3000 feet. It should be noted that the same procedure was applied to all aircraft irrespective of the "best" upper segment descent angle as defined for the various aircraft types by their design characteristics.

A recent study of the two-segment procedure indicates that the optimum descent angle for the upper segment would be expected to vary from 3° to 6°, depending on the aircraft.[22]

c. 4° Approach Profile

A 4° approach glide slope procedure was also investigated for 1981 and 1987 for all aircraft types. This procedure was modified from the ATA-recommended 3° landing procedure, illustrated earlier in Figure 2-5, by simply changing the last 3° landing segment to a 4° approach path.

2.5.2.2 Takeoff Profile Modification

a. Baseline Takeoff Profile

The standard takeoff profiles were calculated assuming a windless, sea level, 59° F day and the ATA standard procedures for all departures.[23] Briefly, this procedure calls for takeoff at maximum power with a speed of V_2* + 10 ktas** and a constant flap setting until reaching 1500 feet above ground level. At this point, power is reduced to maximum climb power or that thrust needed to maintain a 1000 fpm rate of climb, whichever is greater. At 3000 feet, the airplane decreases the climb angle and accelerates at a rate of 1 kt/sec. Flaps are retracted as speed permits. At a speed of 250 ktas, climb is resumed in a clean configuration. Figure 2-8 shows this profile schematically.

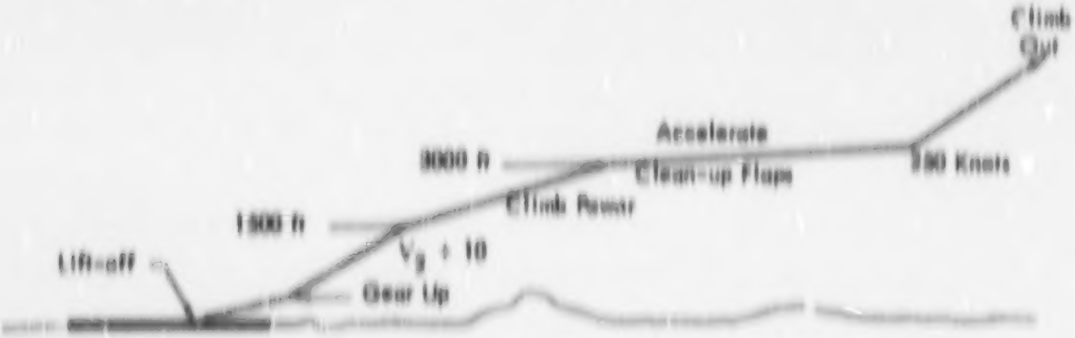

Figure 2-8. Typical Takeoff Profile

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*Speed necessary to maintain minimum climb gradient.

**Ktas = Knots air speed.

b. Power Cutback Takeoff Profile

For this study, the general shape of the power cutback profile, shown in Figure 2-9, closely approximated that recommended by the Airline Pilot's Association (ALPA) procedure. However, the thrust reduction was equal to or greater than that allowed for the FAR 36 certification procedure. The thrust reduction achieved by the ATA takeoff procedure, used for the baseline, and the reduction recommended by ALPA are substantially less than the reduction permitted by the FAR 36 procedure (see Table 2-12 for a comparison of these procedures, along with the procedure used for this study).

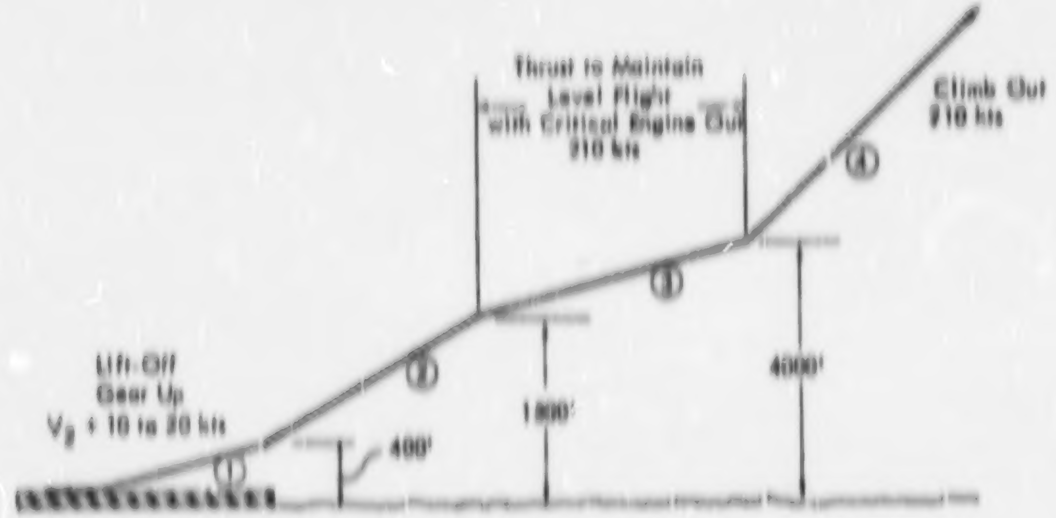

Figure 2-9. Power Cutback Takeoff Profile Used for This Study

The minimum power setting employed during the power cutback segment (number 3 in Figure 2-9) was that which just allowed level flight with critical engine out. This procedure resulted in a varying climb gradient and reduced thrust, relative to maximum takeoff thrust, depending on the number of engines, as indicated in Table 2-13. According to the last column of that table, the average climb gradient during power cutback for 2-, 3-, and 4-engine aircraft was close to that estimated by the

Table 2-12

Takeoff Climb Procedures with Reduced Power Setting

Segment	Parameter	ATA[23]	ALPA[24, 26]	FAR 36[25]	This Study
1	Altitude	● 0-1500'	● 0-400'	● 0-1000' – 3-Eng or less 0-700' – 4-Eng	Same as ALPA
	Power	● Takeoff	● Takeoff	● Takeoff	
	Speed	● ≈ V_2 + 10 kts	● V_2 + 10 to 20 kts	● V_2 + 10 kts	
	Flaps	● Takeoff	● Takeoff	● Takeoff	
2	Altitude	● 1500-3000'	● 400-1500'	↓	Same as ALPA
	Power	● ≈ Maximum Climb Power or Power for 1000' fpm Climb	● Takeoff		
	Speed	● ≈ V_2 + 10 kts	● Accelerating		
	Flaps	● Optimum	● Retracting		
3 (Cutback)	Altitude	● 3000'	● 1500-4000'	● 1000' (min.) – 3-Eng or less 700' (min.) – 4-Eng	● 1500 - 4000'
	Power	● Same as for Segment 2	● Thrust required for one engine out gradient**	● Thrust required for level flight (one engine out) but not less than thrust for 4 percent gradient	● Thrust required for level flight with one engine out
	Speed	● 1 kt/sec Accelerating*	● 210 kts	● V_2 + 10 kts	● 210 kts
	Flaps	● Retracting	● Up	● Takeoff	● Up
4	Altitude	● > 3000'	● > 4000'	↓	Same as ALPA
	Power	● Climb	● Climb		
	Speed	● 250 kts	● 210 kts		
	Flaps	● Up	● Up		

*Assumed

**Climb gradient γ' (with one engine out) not less than:[26]

1.2% for 2-engine aircraft
1.5% for 3-engine aircraft
1.7% for 4-engine aircraft

Climb gradient (all engines operating) $\gamma = \frac{N\gamma'}{N-1} + \left(\frac{1}{N-1}\right)\frac{D}{L}$ for L/D = 10 (see Appendix D of Reference 2 for derivation)

12.4% for 2-engine aircraft
7.3% for 3-engine aircraft
5.6% for 4-engine aircraft

simple aerodynamic performance model defined earlier in Section 2.5.2.1. From this model, one can predict that for all engines operating at the power necessary to maintain level flight with critical engine out, the climb gradient in percent is:

$$\text{Climb Gradient} = 100\left(\frac{1}{N-1}\right)\left(\frac{\text{Drag(D)}}{\text{Lift(L)}}\right) \quad \text{, percent}$$

where N = number of engines.

Table 2-13

Average Climb Gradient and Relative Thrust During Power Cutback Condition

Number of Engines (N)	Reduced Thrust* / Maximum Takeoff Thrust		Climb Gradient	
	Minimum Takeoff Weight	Maximum Takeoff Weight	Actual* %	Predicted** %
2	0.74	0.75	9.3	10
3	0.61	0.68	5.3	5
4	0.47	0.64	3.2	3.3

*Average values used in this study for minimum and maximum takeoff weight for all aircraft.

**Predicted climb gradient = 100 1/(N - 1) (Drag/Lift) for power setting equal to that required to maintain level flight with critical engine out.

The values of the predicted gradients given in Table 2-13 are based on a typical lift-to-drag ratio of 10 to 1. The resulting climb gradient employed for the power cutback alternative in this study corresponds to the allowed FAR 36 procedure for 2- and 3-engine aircraft and is about 20 percent below the FAR 36 procedure for 4-engine aircraft. The gradients are also about 35 to 40 percent below those allowed by the ALPA power cutback procedure. Although the power cutback climb gradients for 4-engine aircraft are not exactly compatible with FAR 36, the difference in noise impact is not large since 4-engine narrow body aircraft constitute a small fraction of the total fleet in 1987. Therefore, the amount of power cutback used for this study is considered essentially equivalent to that allowed by FAR 36.

2.5.2.3 Night Curfew

Two alternatives are involved. The first (curfew A), removed all operations between 2200 and 0700 and rescheduled them to the daytime period (0700-2200). The second (curfew B), eliminated all nighttime operations, i.e., any landings and takeoffs between the hours of 2200 and 0700. Figure 2-10 illustrates the change in hourly operations that would occur at a typical airport with these two curfew options.

2.5.3 Combined Source and Operation Modifications

Two composite alternative scenarios were evaluated.

- For 1981, this consisted of two-segment (6°/3°) approach plus power cutback plus SAM 8D/3D retrofit.
- For 1987, this consisted of two-segment (6°/3°) approach plus power cutback plus SAM 8D/3D retrofit plus FAR 36-10 for new production aircraft.

2.5.4 Receiver Modifications

The receiver/land use alternatives which were considered in this study are residential land acquisition and relocation and residential noise reduction treatment. The land acquisition/relocation alternative consists of simply the purchase of the incompatible land in the airport environs at fair market value plus an allowance for the basic moving cost to which each household is entitled as a result of the residential land acquisition. The residential noise reduction alternative consists of providing all homes within various L_{dn} contours with varying degrees of noise reduction treatment.

Costs for various levels of residential noise reduction treatment are examined on the basis of labor and material costs. The economics of these receiver land use

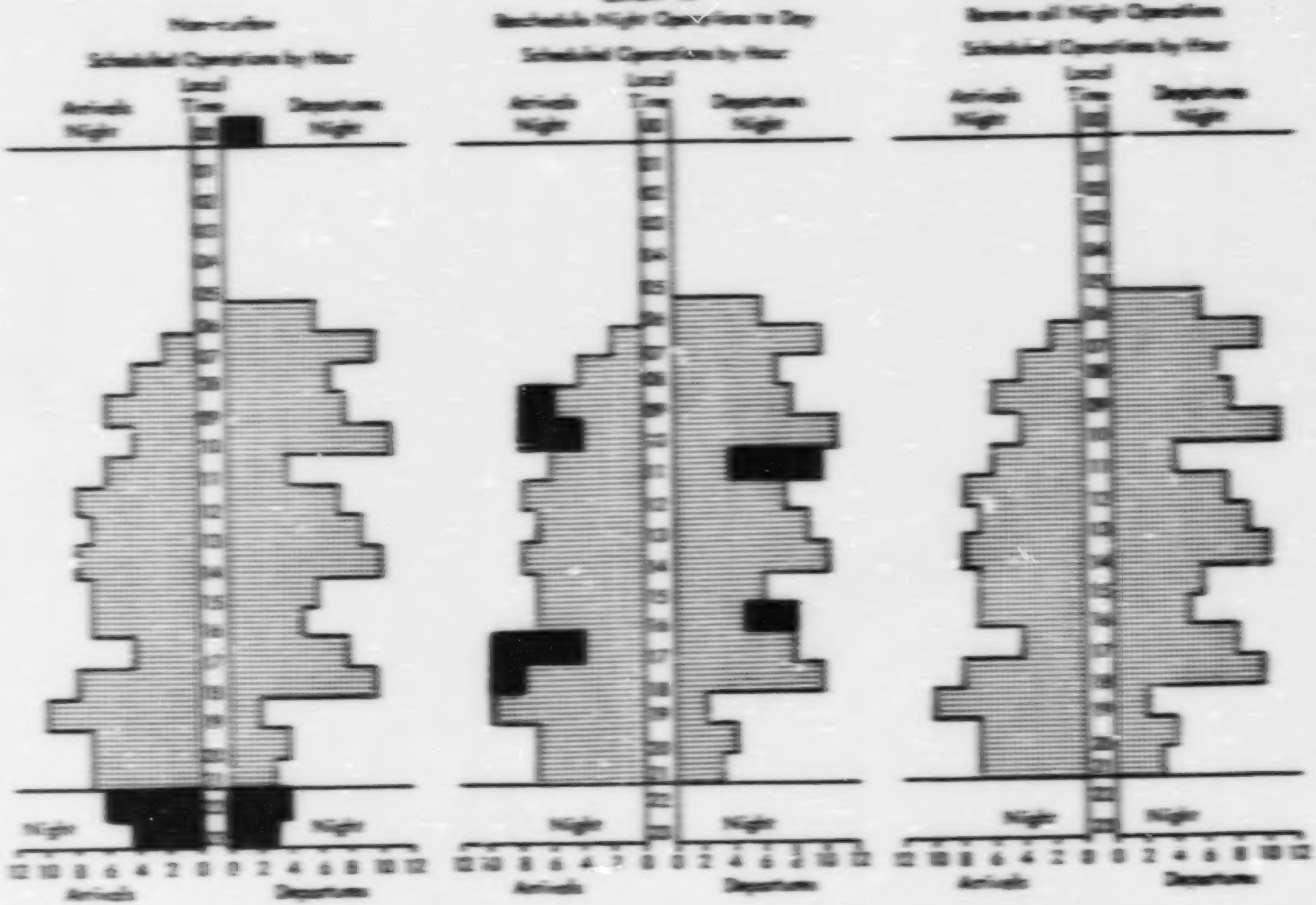

Figure 2-10. Example of Change in Hourly Operations with Curfew Alternatives at a Typical Airport

alternatives is considered in more detail in the next section. The demographic data necessary to define the number of residences involved within any noise contour is considered in Section 2.7 on noise impact analysis. Considered here is the degree of residential noise reduction assumed and criteria for compatible land use.

2.5.4.1 Residential Noise Reduction Treatment

For application to this program, the residential noise reduction alternatives required that detailed cost and resulting noise reduction performance data be utilized. This information was to be drawn from the available literature. Results of several studies made in this area are summarized in Reference 27. The cost and performance data desired were conveniently available in detail and for the largest sample of homes (20) from a previous Wyle study[28] conducted for the Los Angeles Department of Airports, so the latter was used as the data source for this report.

The original data for the LAX study was expressed in Reference 28 in terms of incremental noise reduction of speech interference levels (SIL)[*] and in 1969 dollars. The noise reduction and cost data are revised, in Appendix B, to: (1) convert the incremental noise reduction, due to treatment, to relative A-weighted noise levels, (2) include a minor correction for the added cost of treating open-beam ceiling homes, (3) interpolate the data to 5, 10, and 15 dB values of incremental noise reduction, and (4) update the costs to 1975 dollars. Table 2-14 summarizes these updated data.

Table 2-14

Estimated 1975 Costs for Residential Noise Reduction Treatment
(See Appendix B for Details)

ΔNR_A, dB(1)	5	10	15
Cost, $/ft^2	2.60	7.42	13.47

(1) Incremental change in A-weighted noise reduction

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[*] The arithmetic average sound level for the octave bands centered at 500, 1000, and 2000 Hz.

No attempt was made to project the cost of a 20 dB increment to the noise reduction since the resulting total noise reduction would only be justified for residences where the outdoor noise level was already generally unacceptable.[28]

The actual average increment in noise reduction achieved by any practical programs would, of course, not necessarily fall at the convenient 5 dB intervals suggested by the above table. These were selected solely for convenience in developing costs of a national program as a function of convenient 5 dB increments in noise exposure.

The actual noise reduction that might be achieved by instigating specific noise reduction changes is indicated in the following table.

Table 2-15

Typical Incremental Reduction in A-Weighted Noise Levels Inside Residences for Three Levels of Treatment[28]

STAGE I	STAGE II	STAGE III
Install: • Forced air ventilation • Weatherstripping and non-hardening calking around doors and windows	Install: • Solid core doors • Double-glazed windows • Ceiling tile or gypsum board	Install: • Ventilator attenuators and glass fibre lining of crawl space ducts • Plywood or moisture-proofed gypsum board on underside of floor joists • Fibrous material between open joists of ventilated attic and open wall joists • Gypsum board at bottom of roof rafters
APPROXIMATE INCREMENTAL REDUCTION IN A-WEIGHTED NOISE LEVELS		
6 dB	8 dB	10 dB

Finally, no attempt is made here to rate the subjective reactions to residential noise reduction treatment. A previous program, involving partial government subsidy for selected residences around Heathrow Airport who volunteered, has received mixed reactions ranging from "very effective" to "very poor".[29] A more ambitious program of a similar nature is now being carried out in England for residences near major highways under the Noise Insulation Regulation 1973 (Statutory Instrument 1973 No. 1363). This regulation provides obligatory and discretionary powers for double glazing and installation of mechanical ventilation for dwellings exposed to an 18-hour (0600-2400) L_{10} of 65 dB(A) caused by highway traffic on new or altered roads.[30] Based on a typical hourly cycle of noise near highways, this would be equivalent to an L_{dn} of approximately 68 dB. This extensive residential treatment program should provide an incremental noise reduction for the affected residences of the order of 8 dB, according to Table 2-15. The reaction to this program will be a more valid basis for judging acceptance of the receiver alternative considered for this study.

2.5.4.2 Criteria for Land Use and Acceptable Noise Environment

Each type of land use can be associated with a characteristic range of human activity. For each of these types of activity, there are criteria for acceptable noise levels thus leading to generally accepted criteria for acceptable noise environments for each type of land use.[27]

Figure 2-11 provides a key to the selection of the appropriate land use/noise compatibility criteria for differing L_{dn} values. For each land use listed in the figure, several interpretations are provided, since there is considerable variability in people's reaction to noise or assessment of a given noise environment. In addition, any given land use category may incorporate a range of activities having varying sensitivities to noise. Further, there may be a considerable range in noise insulation of buildings that might be found suitable for a given activity. Taking into account such variables, the noise compatibility interpretations must be used as guides to land use planning and should not be blindly applied as inflexible criteria.

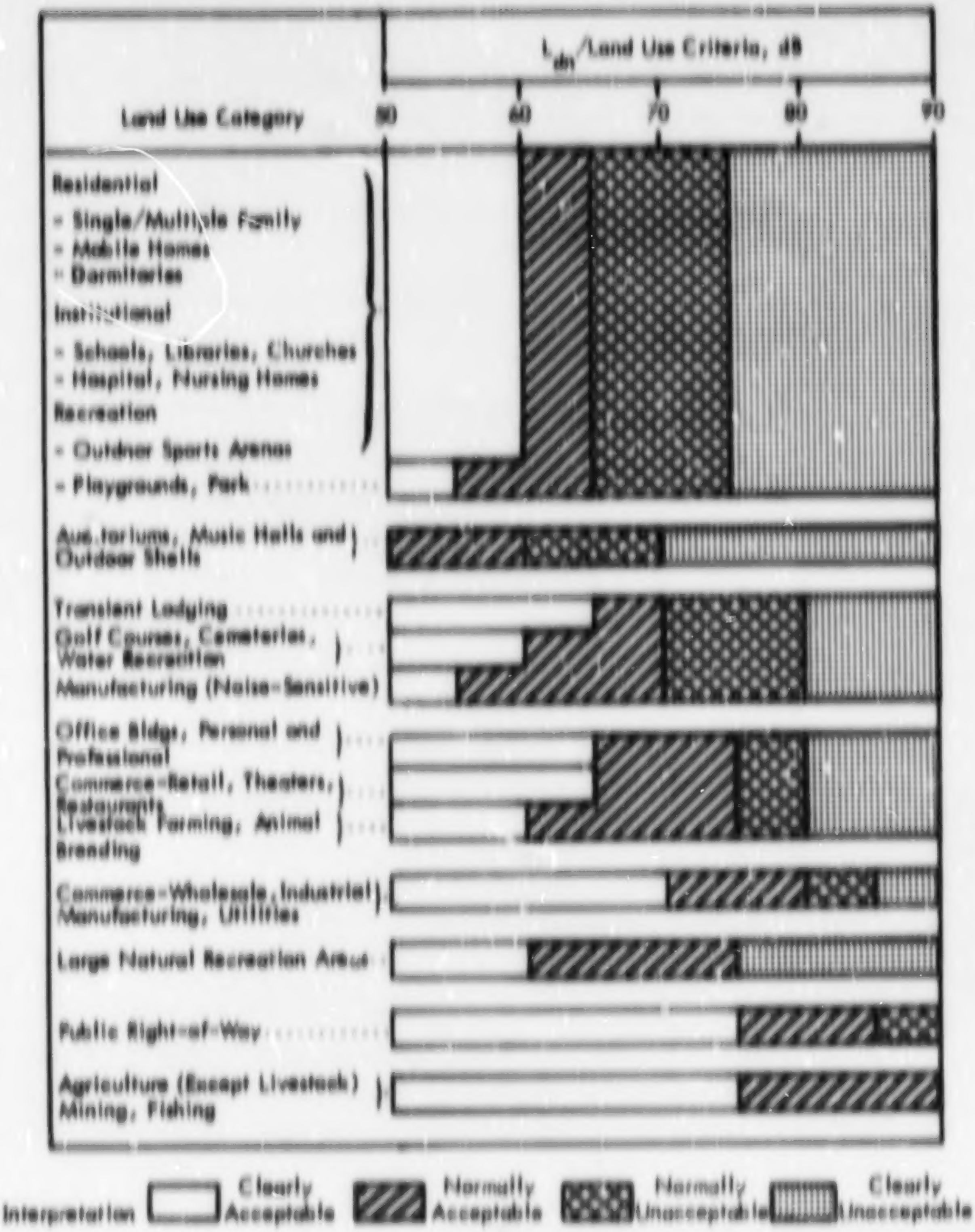

Figure 2-11. Land Use/Noise Exposure Planning Guides[27]

To provide for some degree of flexibility in setting limits, the L_{dn} band for many of the compatibility interpretations in Figure 2-11 provide a range of L_{dn} values where boundaries may be modified by local considerations.

Major factors to consider in adjusting or selecting a specific L_{dn} criteria for a given land use include the following:

a. Previous community experience with the planned noise exposure.

b. Local building construction.

c. Existing noise environment due to other urban or transportation sources.

d. Time period of land use activities. The noise exposure, as expressed by L_{dn}, considers both daytime and nighttime activity with a 10 dB weighting factor for nighttime. This procedure is particularly appropriate for residential land use considerations, but may lead to over estimation of L_{dn} values for work activities or land uses which are confined to daytime hours only.

The interpretations of what noise levels may generally be considered acceptable or unacceptable as a function of land use category in Figure 2-11 are expressed in more definitive terms below.

Clearly acceptable: The noise exposure is such that the activities associated with the land use may be carried out with essentially no interference from noise sources. (Residential areas: both indoor and outdoor noise environments are pleasant.)

Normally acceptable: The noise exposure is great enough to be of some concern, but common building constructions will make the indoor environment acceptable, even for sleeping quarters. (Residential areas: the outdoor environment will be reasonably pleasant for recreation and play.)

Normally unacceptable: The noise exposure is significantly more severe so that special building construction is necessary to ensure adequate performance of activities. (Residential areas: barriers should be erected between the site and prominent noise sources located on the ground to make the outdoor environment tolerable.)

Clearly unacceptable: The noise exposure at the site is so severe that construction costs to make the indoor environment acceptable for performance of activities would tend to be prohibitive. (Residential areas: the outdoor environment would be intolerable for normal residential use.)

For this report, all noise-sensitive land, such as single family residential, etc., which lies within any L_{dn} 65 contour, is considered a general indication of incompatible land use. Thus, the residential noise reduction treatment alternative outlined in the preceding section is applied only to the degree necessary to reduce noise inside residences to levels corresponding to an exterior level less than L_{dn} 65 dB for untreated homes. Thus, residences inside an L_{dn} 65 to 70 dB zone would only require a noise reduction treatment of 5 dB; those inside the L_{dn} 70 to 75 dB zone could use up to 10 dB additional noise reduction, etc.

More conservative criteria for noise-sensitive land use have been utilized in earlier preliminary studies of noise impact around airports and possible aeronautical, operational, and land-use alternatives for reducing this impact.[3, 32] Although the most recent criteria, summarized in Table 2-16, show a desired level of L_{dn} 55 for zero impact in residential areas, these previous studies limited their evaluation to the estimated cost and effectiveness for protection down to an L_{dn} of 60 dB. However, due primarily to the lack of definitive and reliable airport noise environmental estimates below an L_{dn} of 65 dB, this was chosen as the lower limit for evaluation of compatible land use in this report. Thus, this report provides a detailed evaluation of the cost and effectiveness of airport noise reduction alternatives for the most severely impacted population and does not include evaluation of the impact for the people living between the L_{dn} 55 and 65 dB contours around the nation's airports.

Table 2-16

Alternate Criteria for Noise-Sensitive Land Areas Based on the EPA "Levels" Document[33,34]

Observer Category	Land Use	Outdoor/Indoor Noise Reduction		Noise Level Criteria	
		Level dB(2)	Windows	L_{dn} dB	L_{eq} dB
1	Residential	15	Open	55	-
2	Hospital	15	Open	55	-
3	Motel and Hotel	15	Open	60	-
4	School Buildings and Outdoor Teaching Areas	15	Open	(60)(3)	60
5	Church	25	Closed	(60)	60
6	Office Buildings	25	Closed	(73)	70
7	Theater	35	Closed	(73)	70
8	Playgrounds and Active Sports	NA	NA	(70)	70
9	Parks	NA	NA	(60)	60
10	Special Purpose Outdoor Areas	NA	NA	-	(1)

(1) Intruding noise shall not exceed existing L_{eq} minus 5 dB.

(2) Where knowledge of structure indicates a difference in noise reduction from these values, the criterion level may be altered accordingly.

(3) Estimated L_{dn} corresponding to L_{eq} specified in last column assuming latter is an 8-hour energy average, L_{eq}(8).

7.6 Noise Environment Analysis – Air Carrier Airports

This section defines the noise descriptor used for this study and describes the method for analyzing the Airport noise environments in terms of this descriptor.

7.6.1 Noise Descriptor

Consistent with findings of the EPA Task Group on Methods for Characterizing Noise Impact, the airport noise levels are defined in terms of the day-night average sound level, abbreviated L_{dn}.[33] The L_{dn} is defined as the A-weighted average sound level in decibels (re 20 microPascals) during a 24-hour period with a 10 dB weighting applied to nighttime noise levels to account for increased sensitivity of people to noise at night.[34] The nighttime period extends from 10:00 p.m. to 7:00 a.m. L_{dn} can be defined mathematically as follows:

$$L_{dn} = 10 \log\left[\frac{15}{24} \cdot \log^{-1}\left(\frac{\overline{L_d}}{10}\right) + \frac{9}{24} \cdot \log^{-1}\left(\frac{\overline{L_n} + 10}{10}\right)\right]$$

where

$\overline{L_d}$ = energy mean A-weighted noise level during the daytime (0700 to 2200)
$\overline{L_n}$ = energy mean A-weighted noise level during the nighttime (2200 to 0700)
$\log^{-1}$ = denotes an inverse logarithm

The 24-hour period is treated as an annual average day for this study with levels of aircraft operations equal to the annual total divided by 365 days.

The actual impact of the airport noise environments is evaluated by first defining the total area inside each L_{dn} noise contour considered (i.e., L_{dn} 65 to 85) from which the total population inside the corresponding L_{dn} contour is estimated. Then, the effective impact is defined in terms of the Noise Unit (NU) Index[6] (more recently called the Equivalent Noise Impact (ENI) Index.[34] This descriptor may be considered as the "equivalent population" which is 100 percent impacted by noise.[34] It is calculated as follows.

For each L_{dn} level there is associated a "Fractional Impact" (FI) which is designed to express the percent "highly annoyed" response to the environment by the equation:

$$FI = \begin{cases} 0.05(L - L_c) & , L > L_c \\ 0 & , L \leq L_c \end{cases}$$

where L is treated as the total acoustic environment (L_{dn}) at any point around the airport – the aircraft noise (L_{dn}(AC)) added on an energy basis to the nonaircraft ambient noise (L_{dn}(Amb)). The quantity L_c is a criterion L_{dn} equal to L_{dn} 55 or the ambient (nonaircraft) level, whichever is higher. The L_{dn} 55 criterion level is consistent with the land use criteria specified in Table 2-16 and represents the level identified by EPA as "requisite to protect public health and welfare with an adequate margin of safety."[34]

The selection of the nonaircraft ambient level as the criterion level, when the former exceeds L_{dn} 55, is based on the desire to evaluate the airport noise impact due only to the intrusive aircraft noise over and above the normal ambient noise. The constant 0.05 in the above expression is based on the findings by EPA that an intruding noise which exceeds the identified (criterion) level by 20 dB will effectively cause 100 percent impact due to annoyance[34] and/or speech interference.[6] Thus, when the difference $(L - L_c)$ is 20 dB, the fractional impact is $.05(L - L_c) = (L - L_c)/20 = 1.0$ (or 100 percent). At intermediate values for L, a linear relationship between $L - L_c$ and degree of human response is assumed; hence, the simple linear expression given is obtained. Since the level L, in the above expression, is the energy sum of the intruding aircraft noise plus the nonaircraft ambient level, the relationship between the aircraft noise level, L_{dn}(AC) and the fractional impact appears as shown in Figure 2-12. When L_{dn}(AC) is close to an ambient L_{dn} of 55 dB or greater, the fractional impact changes very slowly and does not actually reach zero until L_{dn}(AC) is substantially below L_{dn}(Amb).

For environmental levels greater than 20 dB above the criterion level, the fractional impact exceeds unity reflecting, in part, the desire to account, at least

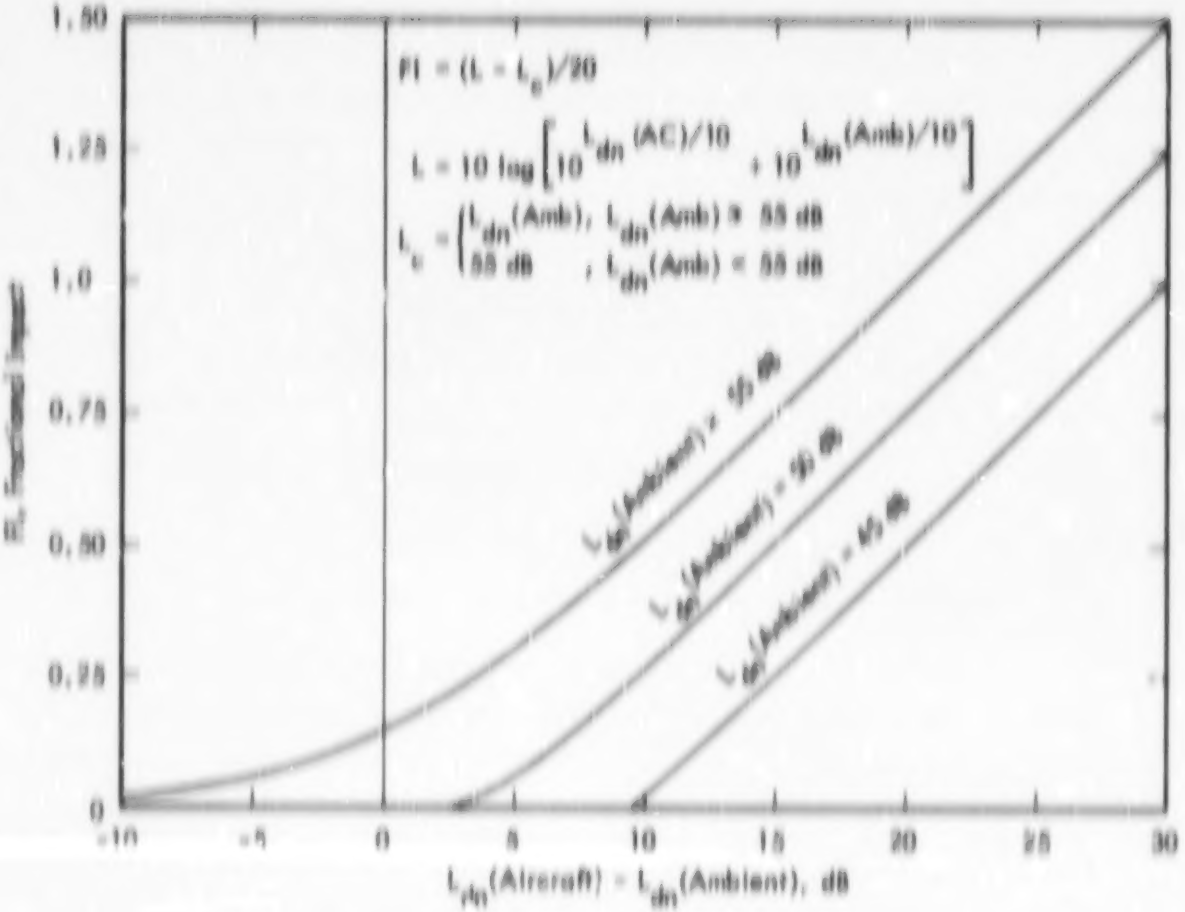

Figure 2-12. Relationship Between L_{dn}(Aircraft), L_{dn}(Ambient) and Fractional Impact (FI)

empirically, for the potential risk of hearing damage for exposure to L_{dn} levels above 75 dB (20 dB above the identified zero-impact level of L_{dn} = 55 dB)[32,34]

Having defined the fractional impact at any point, the overall noise impact in terms of Noise Units (or Equivulent Noise Impact) is essentially the summation of the fractional impact at each point around the airport multipled by the resident population associated with that point or

$$\text{NU (or ENI)} = \sum_{i=1}^{N} P_i(L - L_c)/20$$

where

P_i = the resident population at the i^{th} point

and

N = the number of "points" used to describe the airport area.

This relationship implies that the intensity and extensity of noise impact can be traded off. Thus, if the criterion level (L_c) is, say, 60 dB, then 200 people exposed to a total L_{dn} (aircraft plus ambient) of 70 dB, or 100 people exposed to a total L_{dn} of 80 dB, or 67 people exposed to a total L_{dn} of 90 dB would, in each case, be equivalent to a noise impact of 100 NU (or ENI = 100). That is,

$$200 \times (70 - 60)/20 = 100 \times (80 - 60)/20 = 67 \times (90 - 60)/20 = 100 \text{ NU}$$

For practical computational purposes, the aircraft noise levels L_{dn}(AC), associated contour areas, and populations were computed in 5 dB contour increments so that the noise impact was determined for people inside the L_{dn}(AC) 65 to 70 dB zone, inside the 70 to 75 dB zone, etc. The method for computing population associated with each contour level will be treated later in Section 2.7.

2.6.2 Airport Noise Environments

Before considering the specific steps involved in computing the noise environments for each AVPORT, it is necessary to define the procedure required to define the time-integrated A-weighted noise levels versus slant range for the air carrier aircraft.

2.6.2.1 Aircraft Noise Levels

For the air carrier aircraft, maximum A-weighted noise levels were available from industry data for most of the current aircraft.[14-19] A-weighted noise levels for other aircraft models (four-engine Turbojets, BAC-111, Caravelle, CV-880, A-300B and STOL) were calculated from aircraft noise data available in Wyle files. To convert these maximum noise levels to time-integrated values of noise exposure level (L_{NE}) required for the computation of L_{dn} values, the following procedure was followed:

Duration Correction

The noise exposure level of a single event such as an aircraft flyover is properly defined as

$$L_{NE} = 10 \log \left[\frac{1}{t_0} \int_0^T \frac{p_a^2(t)}{p_{ref}^2} dt \right], \quad dB$$

where:

T = the total duration of the flyover noise (effectively the duration of the period during which the noise is within about 30 dB of its maximum value)

$p_a(t)$ = the A-weighted sound pressure time history

p_{ref} = the reference pressure (20 micro Pascals)

t_0 = the reference duration equal to 1 second

L_{NE}, which can be considered as the noise energy of the event, is more conveniently given by:

$$L_{NE} = 10 \log \left[\left(\log^{-1} \frac{L_A(MAX)}{10} \right) \cdot t_e \right] \quad , \text{dB}$$

or

$$L_{NE} = L_A(MAX) + D_A \quad , \text{dB}$$

where

$$D_A = 10 \log (t_e) \quad , \text{dB re 1 second}$$

and

t_e = the equivalent duration of the single event and equal to the duration of a single event with the same energy as the actual event and a constant level equal to $L_A(MAX)$

At the time this study was initiated, the most substantial body of A-weighted aircraft noise data available was summarized in Reference 35. This provided detailed measurements as a function of slant range $L_A(MAX)$, L_{NE}, maximum tone-corrected perceived noise level (PNLTM) and effective perceived noise level (EPNL) for four different aircraft – a pure turbojet (KC-135) and three different turbofan aircraft B-707-320B with four JT3D engines, B-727 and DC-9 with three and two JT8D engines respectively. From these data it was possible to derive empirical expressions relating the effective duration correction D_A to slant range.

In addition to obtaining D_A as indicated earlier from $L_{NE} - L_A(MAX)$, a good approximation to this time duration correction was obtained from the difference between EPNL and PNLTM as

$$D_A \approx \text{EPNL} - \text{PNLTM} + 10.3, \quad \text{dB re 1 second}$$

The 10.3 dB term is made up of a 10 dB correction to normalize the duration correction to 1 second instead of 10 seconds as used for EPNL and a 0.3 dB correction to account for the fact that time integration for EPNL is carried out only over the period when PNLT is within 10 dB of its maximum value. Carrying out the integration over the entire noise event (or at least the top 30 dB) adds about 0.3 dB more to the time-integrated level.

The regression lines for D_A computed directly and indirectly according to the above two equations are shown in Figure 2-13. These lines were derived from a least squares fit using 160 to 250 data points per aircraft. The regression lines for landing and takeoff have been averaged together for each aircraft for convenience. Figure 2-14 shows the observed data for D_A (computed from the preceding equation) from all the 707 flights reported in Reference 35. The difference between duration corrections for landing and takeoff at the same slant range were not systematically different for any aircraft. In addition, due to their nearly identical regressions lines, the results for the JT8D powered aircraft (727 and DC-9) were combined. By all measures the data consistently grouped into the three aircraft categories specified in Figure 2-13. Differences in D_A between these categories were considered significant.

It is clear that values of D_A computed directly from $L_{NE} - L_A(MAX)$ are nearly the same (within ± 1 dB at the most) as the values computed indirectly from EPNL - PNLTM. The values of D_A computed directly from $L_{NE} - L_A(MAX)$ were subject to two small errors. 1) $L_A(MAX)$ was actually the A-weighted level at the time of maximum PNLT instead of at the time of maximum A-weighted level,[36] and 2) L_{NE} and $L_A(MAX)$ were not corrected to standard temperature and relative humidity conditions. Therefore, for this study the values for D_A were computed indirectly from EPNL - PNLTM, both which were corrected to the standard conditions.

The final expressions are given below along with the average correlation coefficient ($\bar{r}$) and number of data points (N) for each average regression line.

1. For two and three engine turbofan aircraft (and wide body aircraft)

$$D_A = 5.72 \log (R, ft) - 9.1, \quad \text{dB re 1 second}$$

$$\bar{r} = 0.797, \qquad N = 380$$

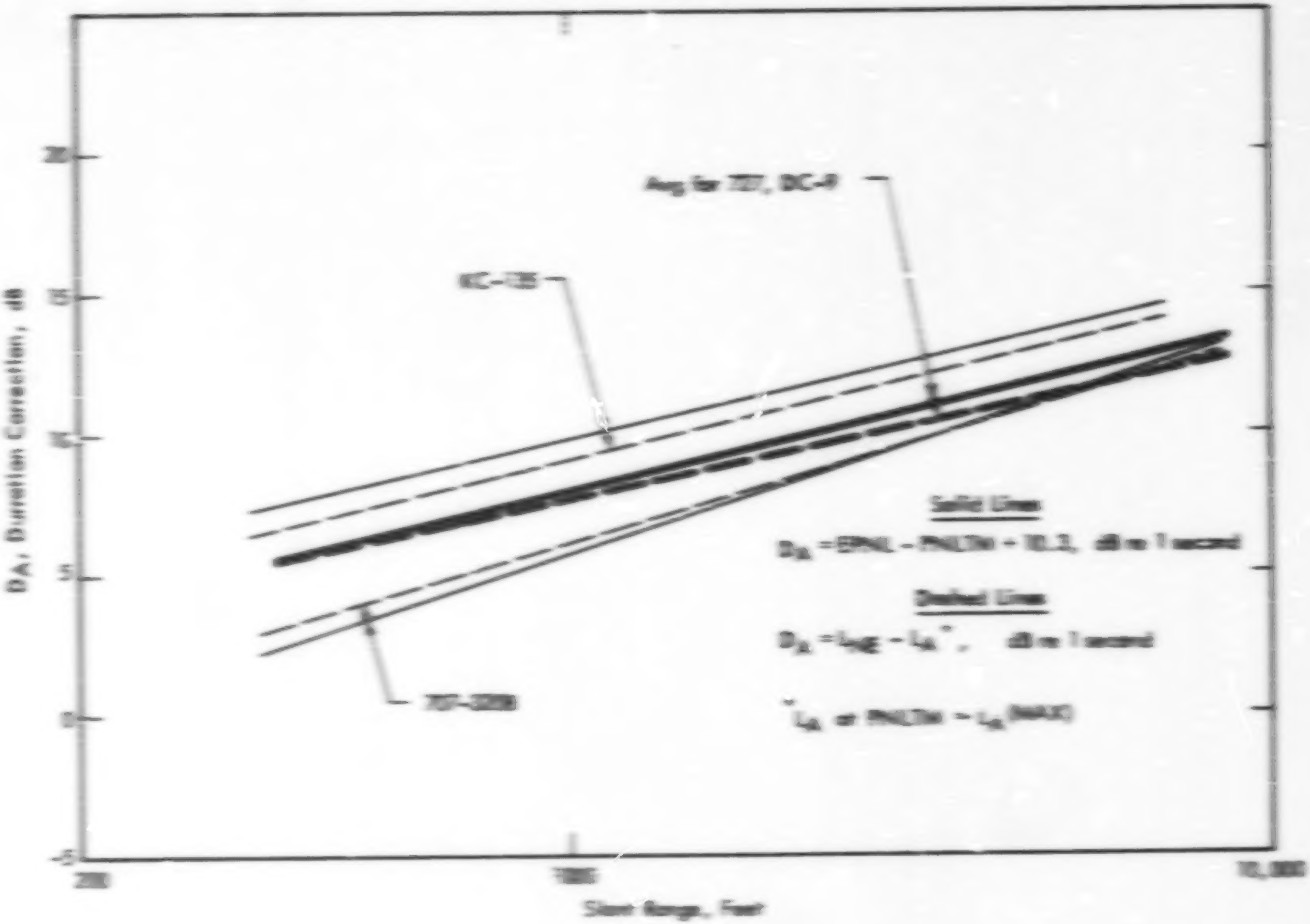

Figure 2-13. Comparison of Regression Lines for Predicting Duration Correction for A-Weighted Aircraft Noise Levels. (Computed from Data in Reference 35)

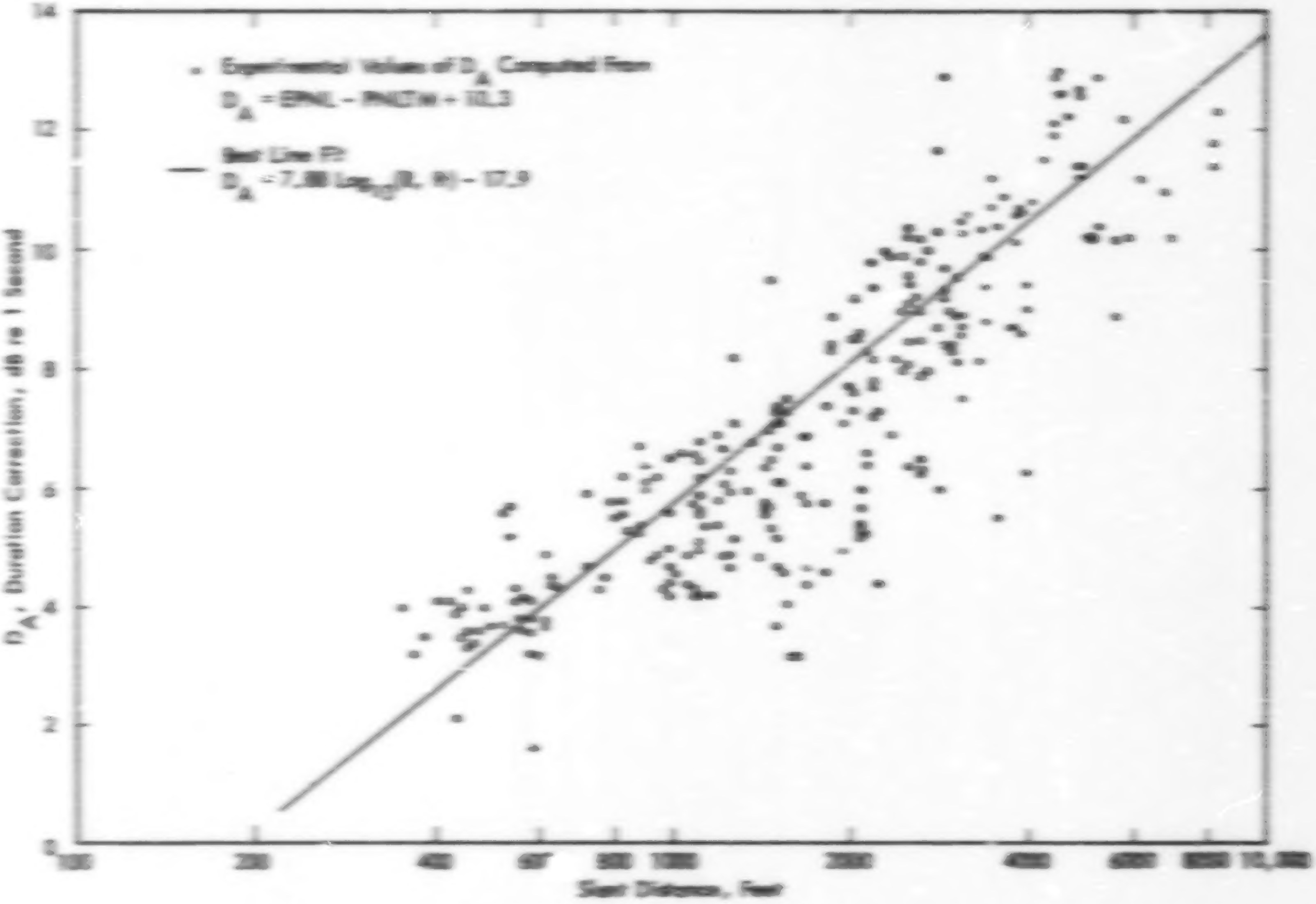

Figure 2-14. Measured Values of Duration Correction for A-Weighted Noise Levels for B707-320B (Adapted from Data in Reference 35)

II. For four engine turbojets

$$D_A = 5.55 \log (R, ft) - 6.8, \quad \text{dB re 1 second}$$

$$\bar{r} = 0.833, \qquad N = 160$$

III. For four engine narrow body turbofan aircraft

$$D_A = 7.88 \log (R, ft) - 17.9, \quad \text{dB re 1 second}$$

$$\bar{r} = 0.854, \qquad N = 260$$

The average standard error in the estimate of D_A from these regression lines is about ±1.5 dB. The range in observed slant distances upon which these regression equations are based is indicated in Figure 2-13 by the lengths of each regression line and extends from less than 400 feet to well over 7500 feet.

A simple linear model for duration of the noise from a moving source,[31] in the absence any propagation attenuation except spreading losses, predicts that the effective duration varies linearly with distance or D_A varies as 10 log (R):

$$D_A = 10 \log (R, ft) - 10 \log V + C$$

where:

V = the velocity of the source

C = a constant dependent on source directivity

The observed nonlinear relationship between effective duration (t_e) and range (R), indicated in the preceding expressions by the slope being much less than 10, is attributed to the combined effects of air absorption and different spectral content of the noise radiated at various angles from the jet exhaust. These effects apparently combine to cause substantial deviations from the ideal linear model over the long distances for which measurements were obtained in the reference study.[35]

Table 2-17 summarizes the sources for the maximum A-weighted noise levels for each aircraft considered in this study and identifies the assignment of the duration corrections, according to the preceding expressions, used to compute noise exposure level (L_{NE}). The identification numbers for the resulting noise curve in the Wyle computer program are also listed. This table also indicates the data sources and/or assumptions made for aircraft not covered by the industry-furnished aircraft noise definition reports. The resulting noise exposure levels for this study are tabulated in Appendix C.

2.4.2.2 AVport Construction

Runway Utilization and Runway Length

Each AVport consisted of a single runway with takeoff and landing operations from both ends along straight flight tracks. The percentage distribution of arrivals and departure directions for the single runway configuration was computed in the following manner:

A reference direction was defined for each of the "23 airports" using one of the existing runways as the reference runway. The reference runway was chosen as the runway with the maximum number of departure operations. It was assumed that the choice of direction is determined by the local prevailing wind condition. Operations along the remaining runways were assumed to also take place on the reference runway. This was done by rotating each of the remaining runways until they matched the direction of the reference runway and thus collapsed into the reference runway as illustrated below.

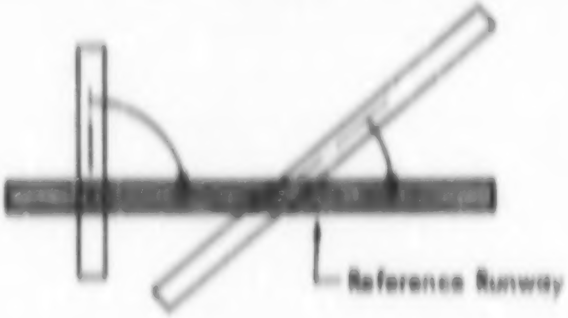

Table 2-17

Summary of Data Sources for A-Weighted Aircraft Noise Levels

Aircraft Type		Data Source: L_A(MAX)[1] 1972[3]	Data Source: L_A(MAX)[1] Future[4]	Data Source: D_A[2]	Noise Curve No.[5] 1972	Noise Curve No.[5] Future
Narrow Body						
B-707-120/320B CV-880	4 Eng. TJ	C[9]	–	II	9	–
B-720	↓	C[9]	–	II	11	–
DC-8-30	↓	C[9]	–	II	4	–
B-707 (Fan)	4 Eng. TF	14	14	III	2	3(R)
DC-8-55,61,63	↓	(6)	(6)	III	2	3(R)
B-727-100,200	3 Eng. TF	15	15	I	10	9(R)
B-737-100,200	2 Eng. TF	16	16	I	12	11(R)
DC-9-30	↓	18	18	I	5	16
BAC 111 (DC-9)	↓	(7)	–	I	5	–
Caravelle	↓	C[9]	–	I	3	–
STOL	↓	–	C[9]	I	–	4(R)
Wide Body						
B-747	4 Eng. TF	17	17	I	13	13(R)
DC-10-10	3 Eng. TF	18	18	I	7	7
L-1011	↓	19	19	I	8	8
A-300B	2 Eng. TF	(8)	(8)	I	15	15

[1] Maximum A-weighted noise level during flyby.

[2] Equation for duration correction to convert L_A(MAX) to noise exposure level ($L_{NE} = L_A(MAX) + D_A$) – see text.

[3] Reference for noise and performance data for current (baseline) aircraft configuration.

[4] Reference for noise and performance data for future aircraft configuration (with nacelle (SAM) retrofit for JT3D/8D aircraft).

[5] Identification number for noise curve in Wyle computer program (see Appendix C).

[6] Noise assumed same as 707-320B/C.

[7] Noise same as DC-9.

[8] Noise same as DC-10-10 minus 1.8 dB.

[9] C denotes values estimated from EPNL data.

Rotation angles were required to be 90 degrees or less. For runways exactly 90 degrees to the reference direction, the rotation direction was assigned clockwise for consistency.

Percentage of total arrival and departure operations in the same and opposite directions as the reference runway, were computed individually for the 23 airports,[1] and mean values for the 23 airports calculated. Additionally, the 23 airports were broken down into three categories: airports with 150,000 annual operations or less, greater than 150,000, but equal to or less than 300,000 annual operations, and airports with greater than 300,000 operations. Mean values of the runway utilization split were again calculated for each of these three annual operations categories. Generally, values in the three annual operations categories were in approximate agreement with the values representing the entire group of 23 airports, which implied, as expected, a lack of significant dependence on actual number of operations at the airport.

For the final values used in this study, the average percent of total operations for arrival and departure in the same and opposite directions as the reference runway were weighted by the actual number of operations for each airport. The result of this process, which provided some degree of representative split between takeoffs and landings operating over the same land area off each end of a runway, is illustrated in Figure 2-15.

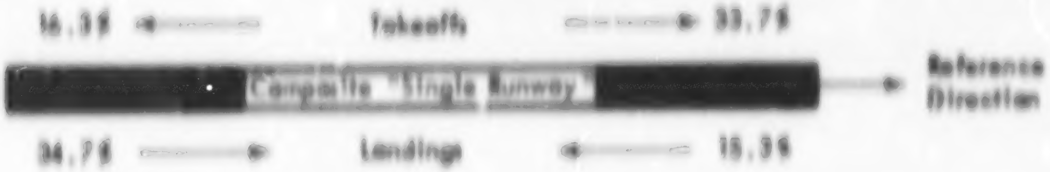

Figure 2-15. Average Runway Utilization Split Based on Average for 23 Airports

Note that for land off the end of the reference runway direction, there would be about twice as many takeoffs as landing overflights. This ratio is approximately reversed for the operations overflying land off the other end of the runway.

The length of each AVport runway was the arithmetic average of the runway lengths from all the airports contained in each AVport sample.[37] For AVports II and III, only the longest runway at each sample airport was used to find the average. The resulting values are.

AVport I	9240 feet
AVport III (Mid-Range)	8060 feet
AVport II	7020 feet

Operational Mix – AVport I

The mix of aircraft types and trip-length assignments for establishing takeoff profiles for AVport I were obtained by simply averaging the total operational mix for all the 23 airports which made up the AVport I sample. For example, the sum of all the B-707-320B aircraft departing on 500 to 1000 mile trips divided by 23 became the corresponding number of operations for this aircraft for AVport I. The same process was followed for all aircraft and trip lengths. Table A-2 to A-4 in Appendix A presents an abbreviated list of the operational mix data. Since the 23 airport operations data also included day and night operations, the corresponding day/night split was also provided inherently for AVport I.

Operational Mix – AVport II and III

For these smaller AVports, the FAA Airport Activity Statistics[10] was used to determine the type of aircraft operating from each of the sample airports listed earlier in Table 2-3 and 2-4. Arithmetic average operations profiles of aircraft type were then constructed in the same manner as for AVport I. Estimates of future operations for 1981 or 1987 were based on the FAA Terminal Area Forecast (1976-1986).[8]

It was assumed that the B-727-100 and BAC-111 series aircraft would be phased out by 1981 and replaced by the B-727-200 and B-737-200 series. Aircraft types which represented less than 1 percent of the total were eliminated. The remaining aircraft types therefore reflected approximately 97 percent of all operations.

Other assumptions for AVport II include:

- Stage lengths were limited to 0 to 500 n mi
- The day/night split was 10 percent night. This percentage is based on the actual count of night operations (2200-0700), averaged for the 30-airport AVport II sample from the current "Official Airline Guide." The percent distribution of night operations by aircraft type was B-727, 20 percent; B-737, 16 percent; DC-9, 28 percent; and two-engine turboprop, 36 percent.

Other assumptions for the Mid-Range (AVport III) model include:

- Day/night split at 10 percent night based on a sample average in the "Official Airline Guide"[13]
- Stage lengths, based on a sample average from the Official Airline Guide, were:

0-500 n mi	500-1000 n mi	1000-1500 n mi	≥1500 n mi
83 %	4 %	4 %	9 %

Tables A-5 and A-6 in Appendix A contain the operational mix data for AVports II and III developed by these procedures.

2.6.2.3 Airport L_{dn} Noise Environments

The preceding paragraphs have defined most of the elements required for computing aircraft noise levels. These are integrated into a computer program developed to model the aircraft activity associated with an airport and to perform the necessary calculations to determine the locations of the L_{dn} contours and L_{dn} values at specified grid points. This computer program was based on the earlier Wyle/DOT NEF computer model[38] which was modified and expanded to provide the more complex computations for this study. The basic parameters necessary for application of the program are summarized in the following along with a few additional details of the input data used for this study.

The Airport System Definition

- Airport Altitude – The airport elevation above mean sea level. The values employed for AVports I, II, and III, based on the average altitudes of the sample airports, were: AVport I, 560 feet; AVport II, 1160 feet; and AVport III, 930 feet.
- Runway Definitions – The runways at each AVport are defined by the locations of their endpoints in a Cartesian coordinate system relative to an arbitrary origin.
- Ground Tracks – The ground tracks lie in the plane of the airport and fall directly beneath the flight path of departing and arriving aircraft. For the AVports, the ground tracks were defined by straight line extensions of the runway centerlines.
- Approach Procedures – The procedures followed by an aircraft on landing approach will normally vary from airport to airport. These approach procedures (e.g., pattern altitudes, descent points, etc.) are termed "airport specific" and must be defined for each individual airport. For all of the AVports in this study, an average approach pattern altitude of 2270 feet was used. This extended from 14.6 n mi before landing threshold to 7 n mi before threshold and was the average approach pattern altitude for the 23 airports.

- Takeoff Restrictions – The standard takeoff procedures specified earlier in Section 2.5.2 were used for all AVports.
- Aircraft Operations – The numbers and types of aircraft operating into and out of the airport in terms of day/night, ground track, and trip length categories for takeoff were specified in the preceding section. The trip length categories are indicative of the takeoff gross weight of the aircraft and are used to determine the takeoff altitude profiles to be assigned to each flight.[1]

In addition to these "airport specific" parameters, the aircraft-dependent noise and takeoff profile data are, of course, also required.

Figure 2-16 illustrates a typical set of contours constructed using the procedures outlined in the preceding paragraphs. The figure shows the baseline 1972 contours for AVport I covering the range of L_{dn} 65 to L_{dn} 85 in 5 dB intervals. Appendix D contains the other contours drawn for this study.

The area within each contour will be shown later to be the basic parameter obtained from these AVport contours which is used to determine the impacted population. The program used to plot these contours also computes the area inside each contour by a standard vector-algebra integration around the contour.[30] Table E-1 in Appendix E tabulates the areas computed directly in this way for AVports I, II, and III and for most of the aeronautical and operational noise reduction alternatives considered for this study. For the other alternatives not listed in these tables (the REFAN 8D/SAM 3D options and the additional alternatives for AVport III not given in Table E-1(c), the estimated contour areas and the procedures used to obtain these estimates are defined in Appendix F.

At this point, it is desirable to examine the method used to define the population impacted within the computed or estimated L_{dn} contours.

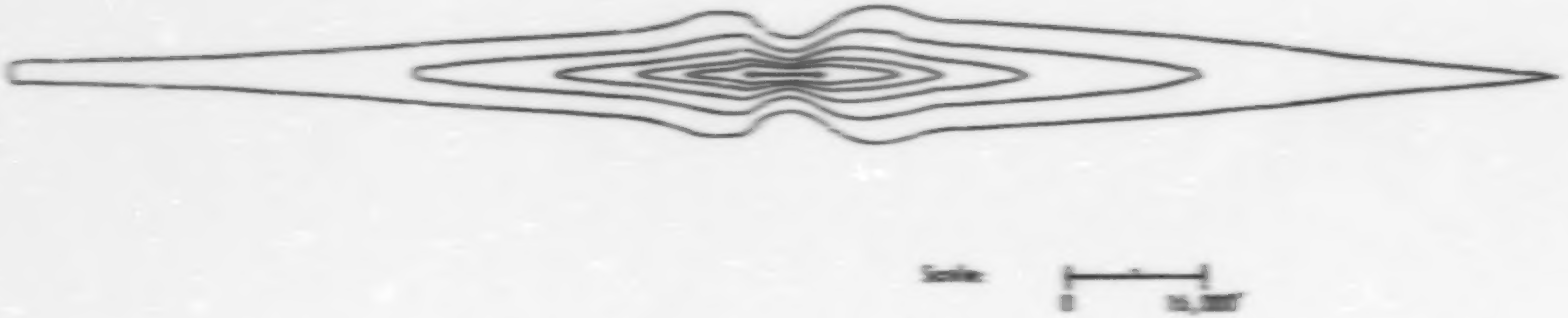

Figure 2-16. Airport I Baseline 1972 L_{dn} 65, 70, 75, 80, and 85 Contours

2.7 Population Models

Two sources of data were available for analysis of the number of people impacted within airport noise contours for the nation. These were:

1. The population within the area enclosed by various Noise Exposure Forecast (NEF) contours evaluated in the 23 airport report — NEF 30, 35, 40, and 45 — for the noise reduction alternatives considered in that report (see Table 2-1).

2. Determination of the average number of people residing within concentric "circle contours" and single runway aircraft noise contours constructed around 130 different air carrier airports covering the range of operations encompassed by AVports I, II, and III.

2.7.1 Population Versus Contour Area From 23 Airport Study

The Noise Exposure Forecast (NEF) noise metric can be approximately correlated with the Day-Night Average Sound Level (L_{dn}) noise metric by the relationship[33]

$$L_{dn} \approx NEF + 35 \quad ; dB$$

Therefore, NEF noise contours constructed around an airport will have a shape very similar to that of L_{dn} contours constructed for the same aircraft and operations. It was, in fact, assumed that if the total areas inside an NEF and an L_{dn} contour around an airport were identical, then the actual shape of the contour would also be essentially the same. Thus, any relationship between total area and population inside NEF contours could also be directly applied to predict the population inside L_{dn} contours at the same airport or group of airports. From the data on population inside the NEF 30 to 45 dB contours for all the cases considered in the 23 airport study, it was possible to construct the relationship shown in Figure 2-17 by the solid line.[1] This illustrates the empirical relationship found between average total contour area per airport and corresponding average population per airport within these NEF contours. This relationship

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[1] For further detail, see Tables 3.1-1 to 3.1-23 in Reference 1.

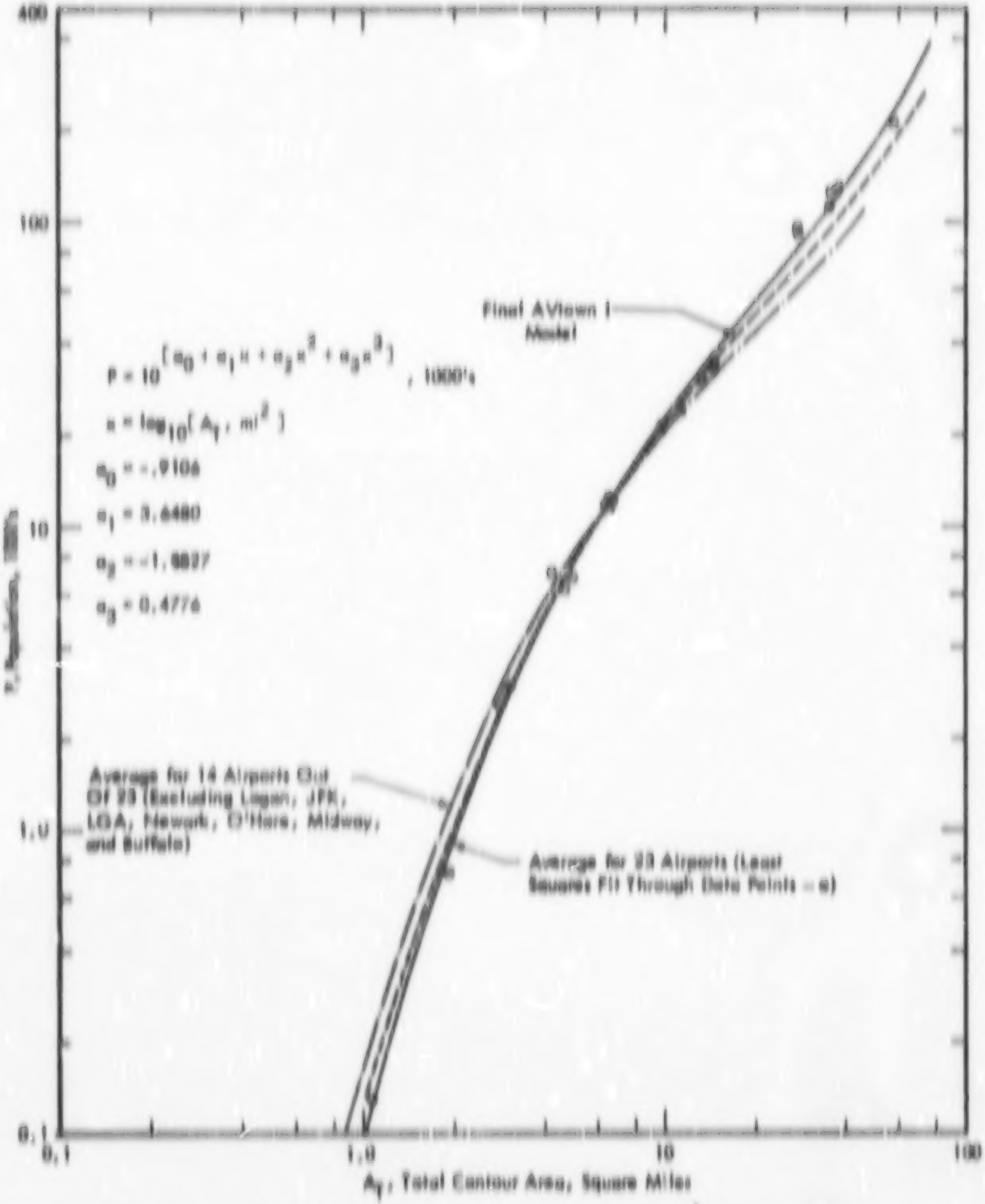

Figure 7-17. Population Versus Contour Area for 23 Airports,[1] 14 Airport Subset and Final AVtown I Model for Air Carrier Airports with More Than 100 Operations Per Day

is plotted on logarithmic scales for both total contour area (A_T) and population (P) to permit a consistent portrayal of the data over its full range. The solid line shown is a least squares fit through the plotted data points which are the total values for all 23 airports, as reported in Reference 1, divided by 23.

However, before such a relationship can be used for all 60 airports falling within the AVport I sample range (> 100 operations per day),[9] it is nesessary to adjust it to account for the fact that impacted population from this 23 airport sample is weighted by the larger airports located in the eastern U.S. which have an above-average population density. Therefore, a reduced sample of 14 out of the 23 airports was selected to examine the average population versus contour area relationship for airports considered more representative of the remaining airports not located in the larger high-density cities. This reduced sample of 14 airports consisted of all of the 23 airports (listed in Table 2-2) with the exception of Boston, Buffalo, Chicago-Midway, Chicago-O'Hare, Cleveland, J.F. Kennedy, La Guardia, Newark, and Philadelphia. The resulting best-fit line for the relationship between average population and average total contour area for these 14 cities is also shown in Figure 2-17 by the dash-dot line. As expected, the latter indicates a significantly lower population for large contour areas than the solid line representing the average for all 23 airports. A best-fit line also was constructed for the average population versus area for the nine largest airports and was about 25 percent higher than the 23 airport line for contour areas above 10 square miles.

Therefore, for application to all 60 airports in the AVport I category, an intermediate line, shown in Figure 2-17 by the dashed line, was constructed by interpolating between the relationships for the 14 airports, representing the average airport and the nine largest airports. This interpolation was based on the relative number of daily operations at the nine largest airports (6530 daily operations in CY 1972)[9] and the remaining 51 airports (16,862 daily operations in CY 1972).[9] Thus, for a given average contour area A_T, if the average population from the nine airport sample was P_9 and from the 14 airport sample was P_{14}, the estimated average population (P_I) for the average AVtown I airport was taken to be

$$P_I = \left(\frac{6530}{6530 + 16562}\right) \cdot P_9 + \left(\frac{16562}{6530 + 16562}\right) \cdot P_{14}$$

The resulting expression for this population versus contour area function for AVtown I airports (for 1972 only) was

$$P_I = 10^{\left[a_0 + a_1 x + a_2 x^2 + a_3 x^3\right]} \quad , 1000\text{'s}$$

where

$x = \log_{10}(A_T, \text{mi}^2)$

$a_0 = -0.9106$

$a_1 = 3.6480$

$a_2 = -1.8827$

$a_3 = 0.4776$

and

A_T = total contour area in square miles

Although simpler algebraic formulations for this relationship were possible, the log - log or power-law form used was, in fact, simple to derive and a convenient form for fitting all of the population data considered in this study.

The application of this population function can now be visualized conceptually as follows. Given the total area inside any L_{dn} contour evaluated around AVport I for any alternative, one can predict the total population inside this contour from the expression stated earlier. Then, by defining a suitable scaling factor, one can project this figure for impacted population for AVport I to the total for the nation around all airports in the AVport I category. However, three questions must be answered before this method can be applied. These are:

1. What is the relationship between the area within the contours constructed for an average actual airport (i.e., the average of the 23 airports) and the area within the contours around the idealized single-runway AVport?
2. What is the proper population contour area relationship for the smaller airports represented by AVports II and III?
3. What are the "suitable scaling factors?"

This last question will be addressed in Section 2.8 dealing with the national model for airport noise impact.

The first two questions are considered next. The answers require examination of the population density pattern around airports as a function of both distance from the airport and its size as measured by the number of daily operations.

2.7.2 Population Density Around 130 U.S. Air Carrier Airports

Population and population density were determined for each of 432 discrete area segments adjacent to each of 130 U.S. air carrier airports.* These data, obtained from a computerized search of 1970 census tapes, were first aggregated and averaged for each of three operational categories (> 100, 40 to 99, and 10 to 39 operations per day) corresponding to AVports I, III, and II respectively. The sample included 54 out of 60 in the AVport I category, 40 out of 55 in the AVport III category, and 36 out of 140 in the AVport II category.[9] The three resulting "AVtowns" provided an unique population data basis for impact analyses of all the nation's airports.

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*This population density analysis was provided to Wyle Research by the Office of Noise Abatement and Control, U.S. Environmental Protection Agency.

The format for the collection and analysis of these population data consisted of a set of 12 concentric rings centered on the geographic coordinates for the midpoint of the main runway at each individual airport. These rings were further divided into 36 10-degree sectors. Radii of 1, 2, 3, 4, 5, 7, 9, 11, 13, 15, 18, and 21 miles were selected for the concentric rings in order to provide a finer degree of data resolution for areas closer to the airport (see Figure 2-18).

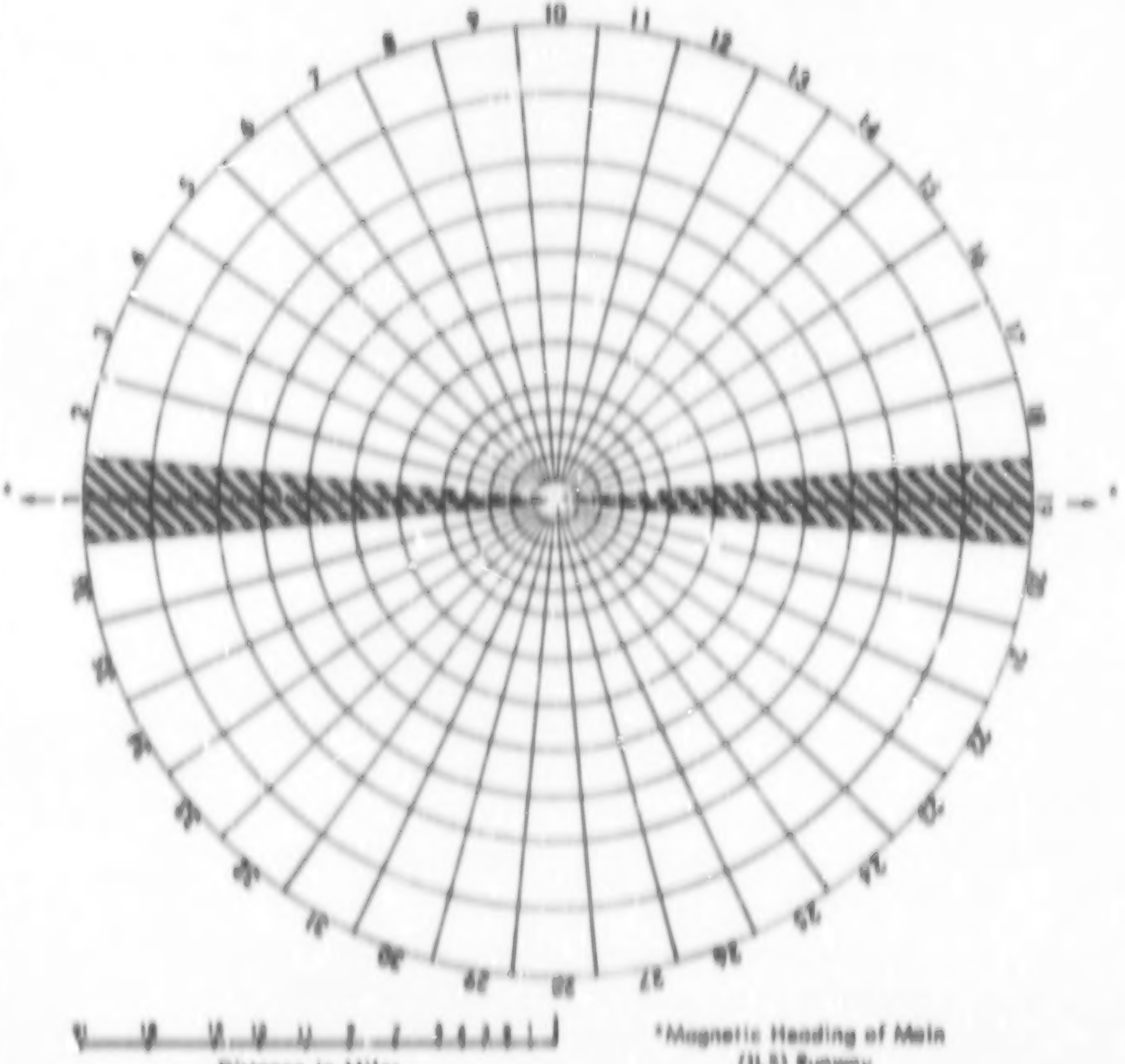
The 10-degree sectors were numbered consecutively in a clockwise direction. Sectors numbers 1 and 19 were aligned with the magnetic bearing of the main ILS runway, or the longest and most heavily utilized runway where no ILS runway existed. Corrections for the magnetic declination from true north were made for each airport to account for the fact that the census geographic coordinates employed in searching the census tapes were referenced to true north.

The 36 azimuthal sectors and the 12 radial rings created 432 sector segments with a fixed spatial relationship to the bearing of the most frequently used runway at each airport. Population could then be assigned to each sector segment by the geo-coordinate computer program using the census population tapes. For each airport, the program simply summed the population, at the block group level of data resolution, for all population centroids falling within each sector segment.

Within each AVport category, the program averaged population data for each sector segment after tabulating and storing the data for each individual airport. Because the AVport II category included only 36 out of 140 facilities, separate AVtowns were calculated for aggregates of 10, 20, 30, and 36 airports to determine whether population density characteristics would stabilize as the sample size increased. No significant population trends were observable after a sample size of 20 airports was reached.

These population data were utilized in two ways:

1. Define the total population inside circular "contours" around the AVtowns as a function of the circle area.



*Magnetic Heading of Main (ILS) Runway

Figure 2-18. Radial and Azimuthal Segmentation of Area Around Airports for Analysis of Population Characteristics

2. Estimate the total population inside each of the L_{dn} contours for the 1972 baseline contour sets for each single-runway AVport – with straight in-out flight tracks.

These two applications provide a rough approximation of the impacted population for two extreme cases:

1. An airport with multiple runways in several directions tending to give more circular contours, and

2. A single runway airport with straight in-out flight tracks.

It was anticipated that a valid population versus contour area relationship would lie somewhere between these extremes. Figure 2-19 illustrates the variation in population density as a function of the radial distance from the main runway center for the three AVtowns.[*] The shaded band shown for each AVtown represents the range of the average population density within each 90 degree segment within any circle. The variation between these 90 degree segments is substantial but apparently random, exhibiting little, if any, consistent pattern for the population density as a function of azimuth. Within each 90 degree segment, the variation in population density from one 10 degree sector to another within any one annular ring was even greater. For example, in the zone between 1 and 13 miles from the AVtown I model, the standard deviation of the population density around any one annular ring relative to the mean value was consistently about 20 to 22 percent. Thus, it was considered necessary and sufficient for this study to further collapse these population density data for the AVtowns into average values as a function of radius only, ignoring the more or less random behavior as a function of azimuth.

For the first application cited above, the average population within a given AVport contour was estimated by determining the population density for each annular segment falling within the contour in question, multiplying by the segment area and then summing over all segments within the contour. This process, illustrated in Figure 2-20, was carried out only with the 1972 baseline contours for each AVport.

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[*] For further detail, see Table I-6, Appendix I.

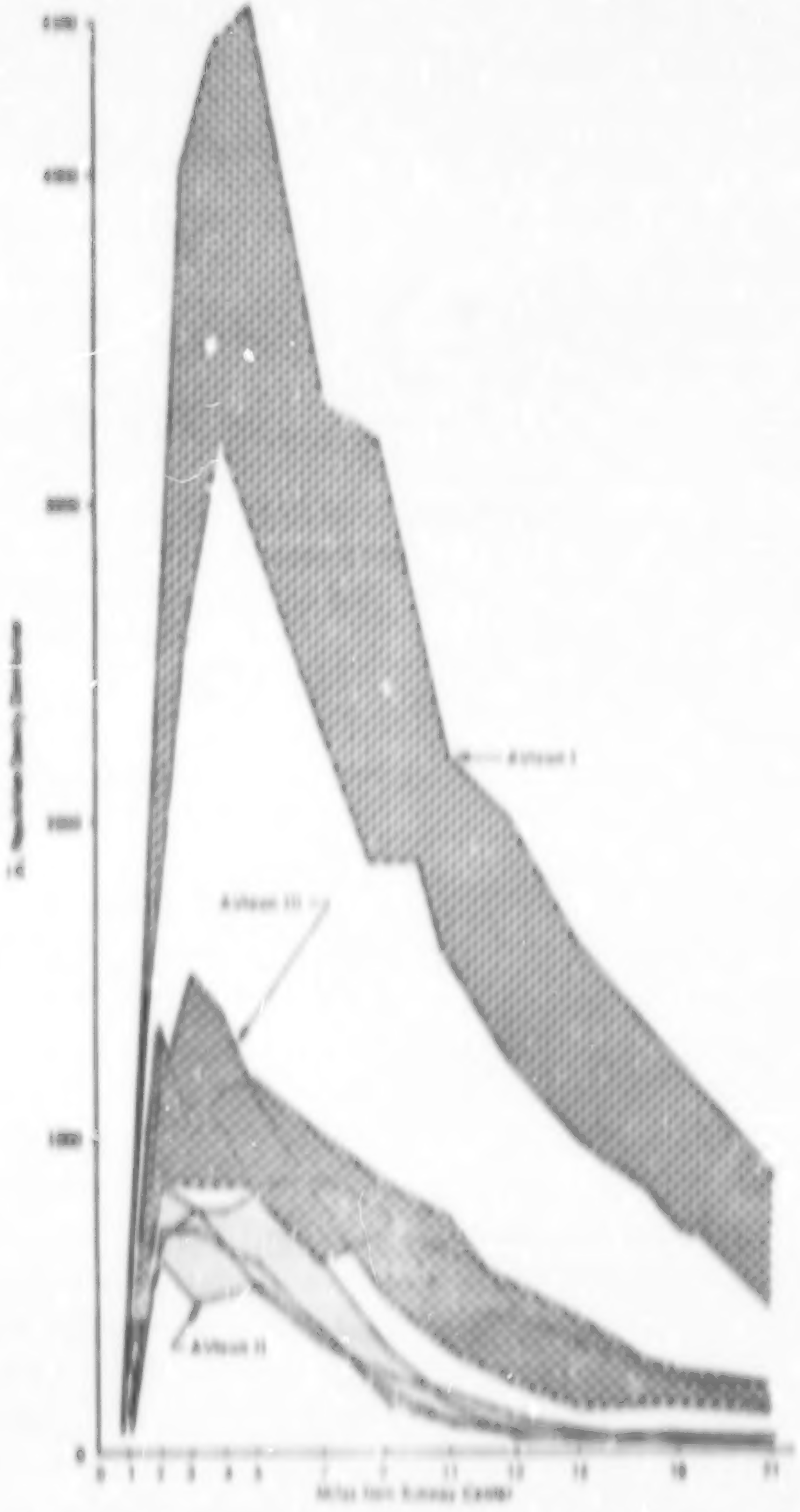
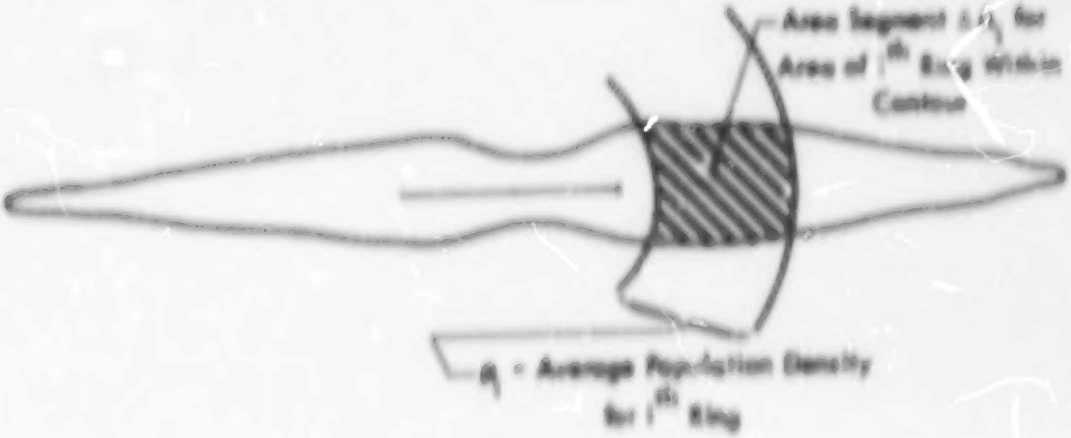


Figure 2-19. Population Density Distributions for AVtowns I, II, and III


Area Segment ΔA_i for
Area of i^{th} Ring Within
Contour
ρ_i = Average Population Density
for i^{th} Ring

Total Population Within Contour $= \sum_i \rho_i \Delta A_i$

Figure 2-20. Illustration of Method for Estimating Impacted Population for Each AVtown for Noise Contours Around Each AVport

For the second application, the total population inside the "circular" contours was determined by essentially the same type of numerical integration except that the total population within each entire annular ring inside any radius was used.

Figure 2-21 compares these resulting values of population as a function of "contour" area for AVtown I with the relationship developed earlier in Figure 2-17 from the 23 airport data. The latter, indicated in Figure 2-21 by the solid line, lies between data for the "circular" (solid circles) and single runway (solid triangle) contours for low values of the total contour area (A_T < 10 square miles) and falls very close to the simple circular contour model for total contour areas from about 10 to 80 square miles for AVtown I.* Thus, these AVtown population data provide at least a qualitative verification of the more exact values for population versus contour area derived from the 23 airport data. The differences between the latter and the estimates of population versus contour area based on the idealized AVport contours and AVtown population profiles are

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*For more detail on total population versus total contour area for "circular contours" see Tables I-9 and I-10, Appendix I.

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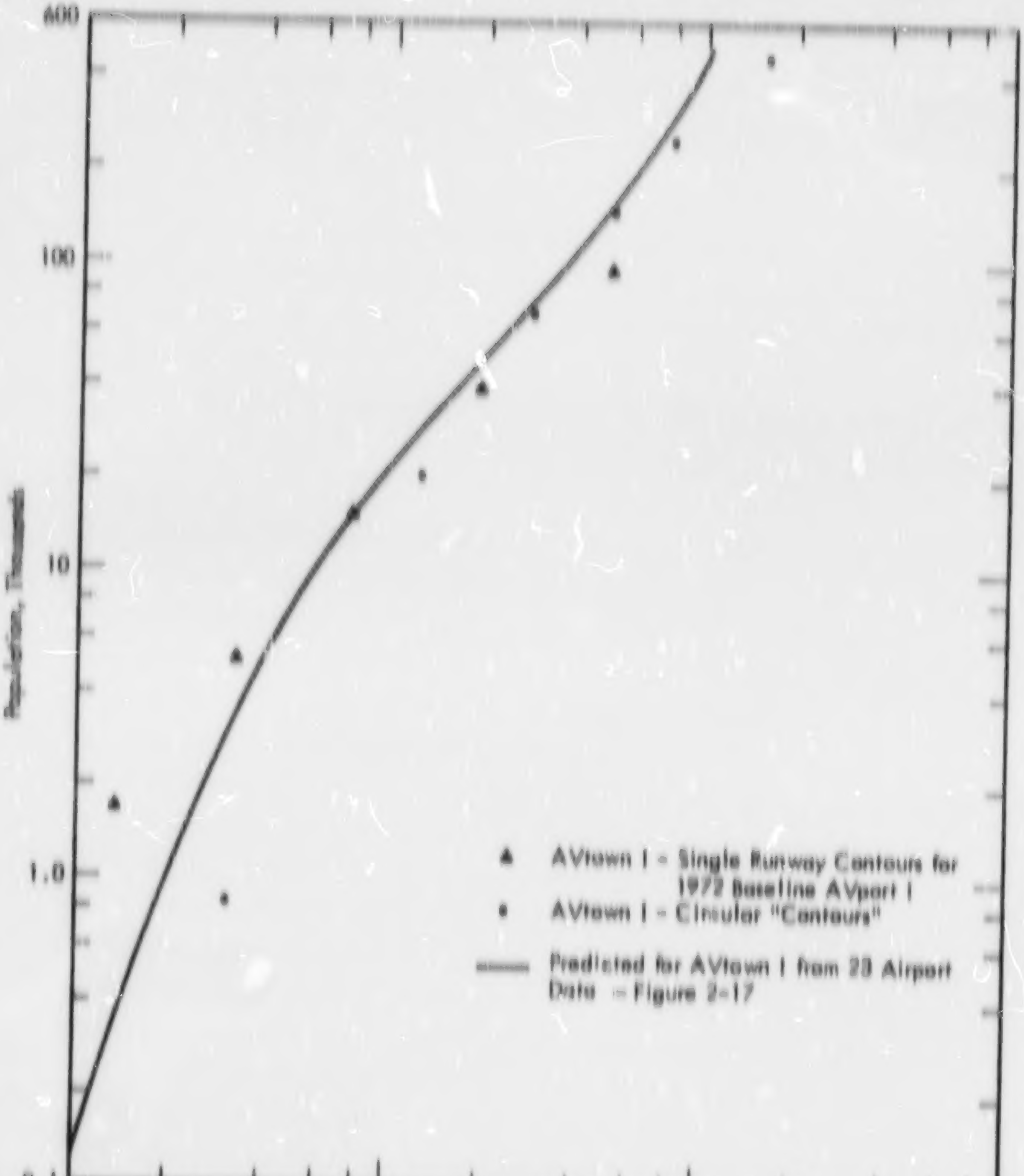

Figure 2-21. Population Versus Contour Area for AVtown I

attributed to the differences between real contour shapes and the idealized shapes constructed for the AVtown models.

2.7.3 Population Models for AVtowns II and III

Based on the data in Figure 2-21, it seems clear that one can use the AVtown population data to indicate the approximate magnitude of the population profile near the smaller airports but that the exact shape of this profile inside real airport noise contours should reflect the relationship indicated by the solid line in Figure 2-21. Thus, the following process was used to adjust this line for AVtown I to be applicable to AVtowns II and III.

First, the population density profiles, as a function of radius, for the three AVtowns, shown earlier in Figure 2-19, were each normalized to their maximum value and replotted on log - log scale as relative population density versus total area of the circle at each radius R. The result is shown in Figure 2-22. This figure indicates that for total circular contour areas from about 30 to 100 square miles, the population density profiles have essentially the same (normalized) shape, differing only in their peak value but that for small contour areas (e.g., closer to the AVports), the relative population density stays more nearly constant for the smaller airports. This is a reasonable result reflecting that the smaller the airport, the closer people can reside to the airport center. Next, the population versus contour area profile in Figure 2-17 for AVtown I was shifted down in direct proportion to the peak population density of AVtowns II and III relative to AVtown I. Finally, the lower end of the profiles were adjusted for small contour areas to correspond to the closer encroachment possible for the smaller airports. The resulting estimates of the effective population versus real contour area for AVtowns II and III are shown in Figures 2-23 and 2-24 respectively. The dashed lines show the profile scaled down from the AVtown I profile while the solid lines indicate the further adjustment made to reflect the close-in encroachment effect for the smaller airports.

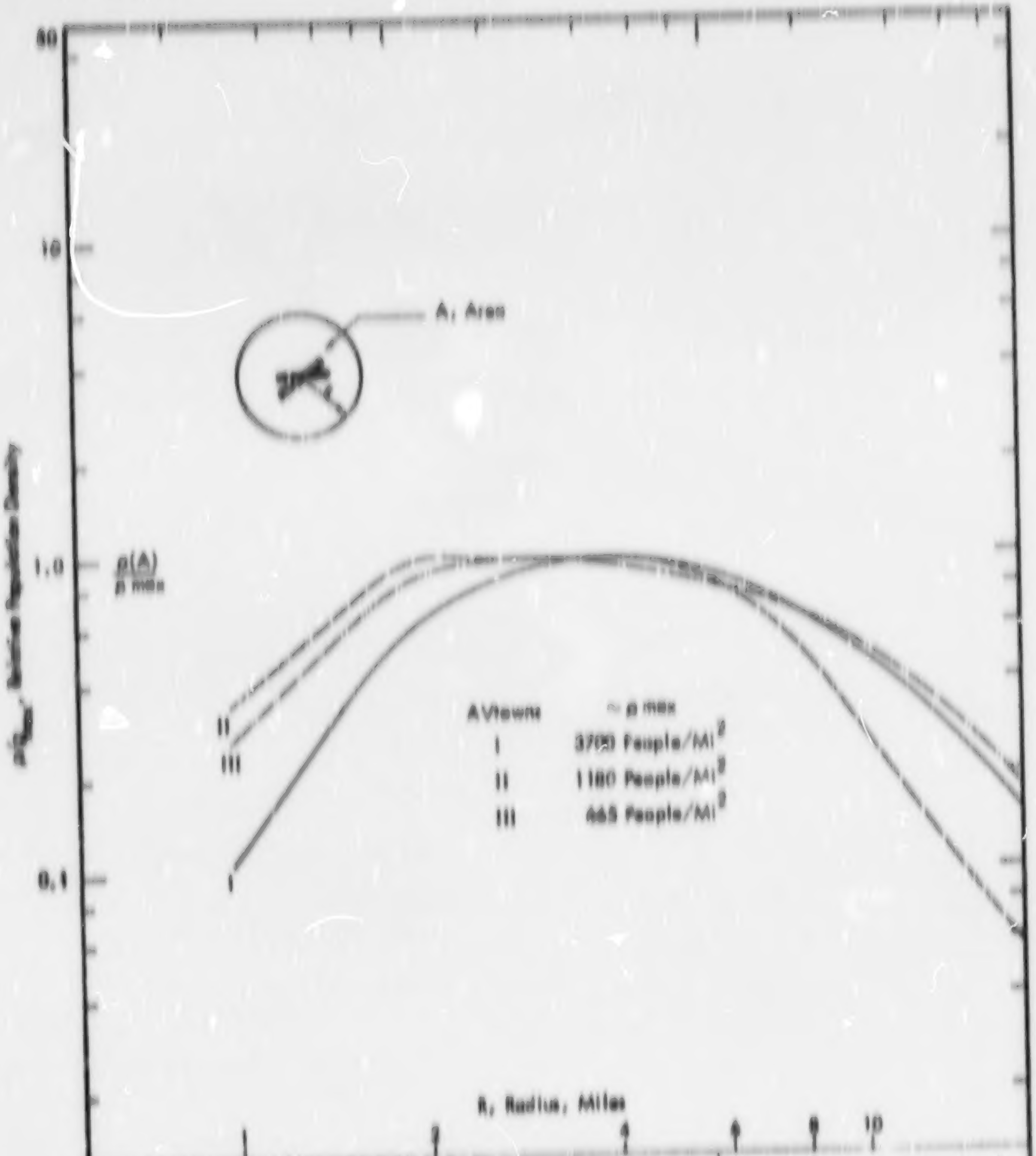

Figure 2-22. Relative Population Density Versus Circle Area

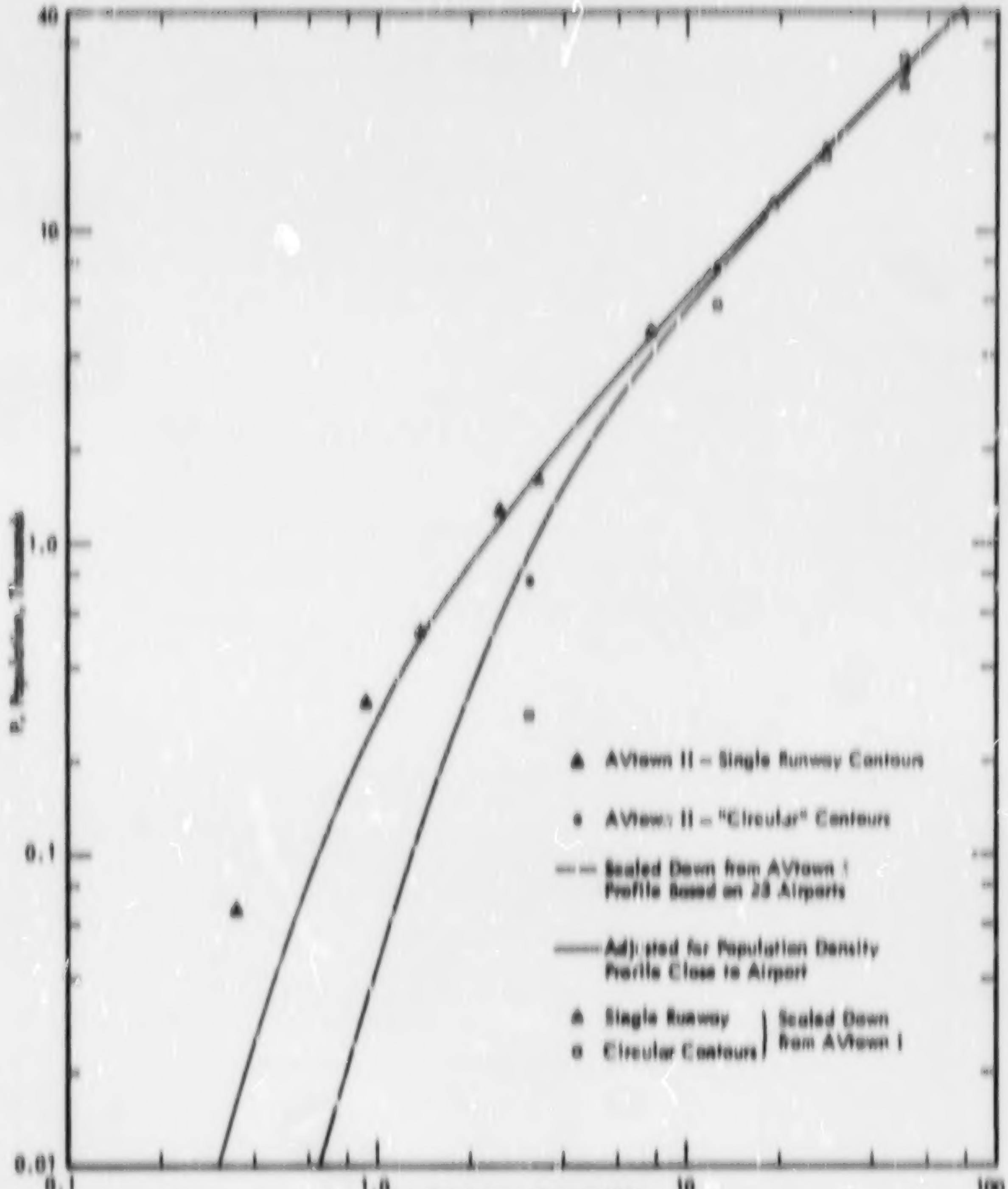

Figure 2-23. Population Versus Contour Area for AVtown II

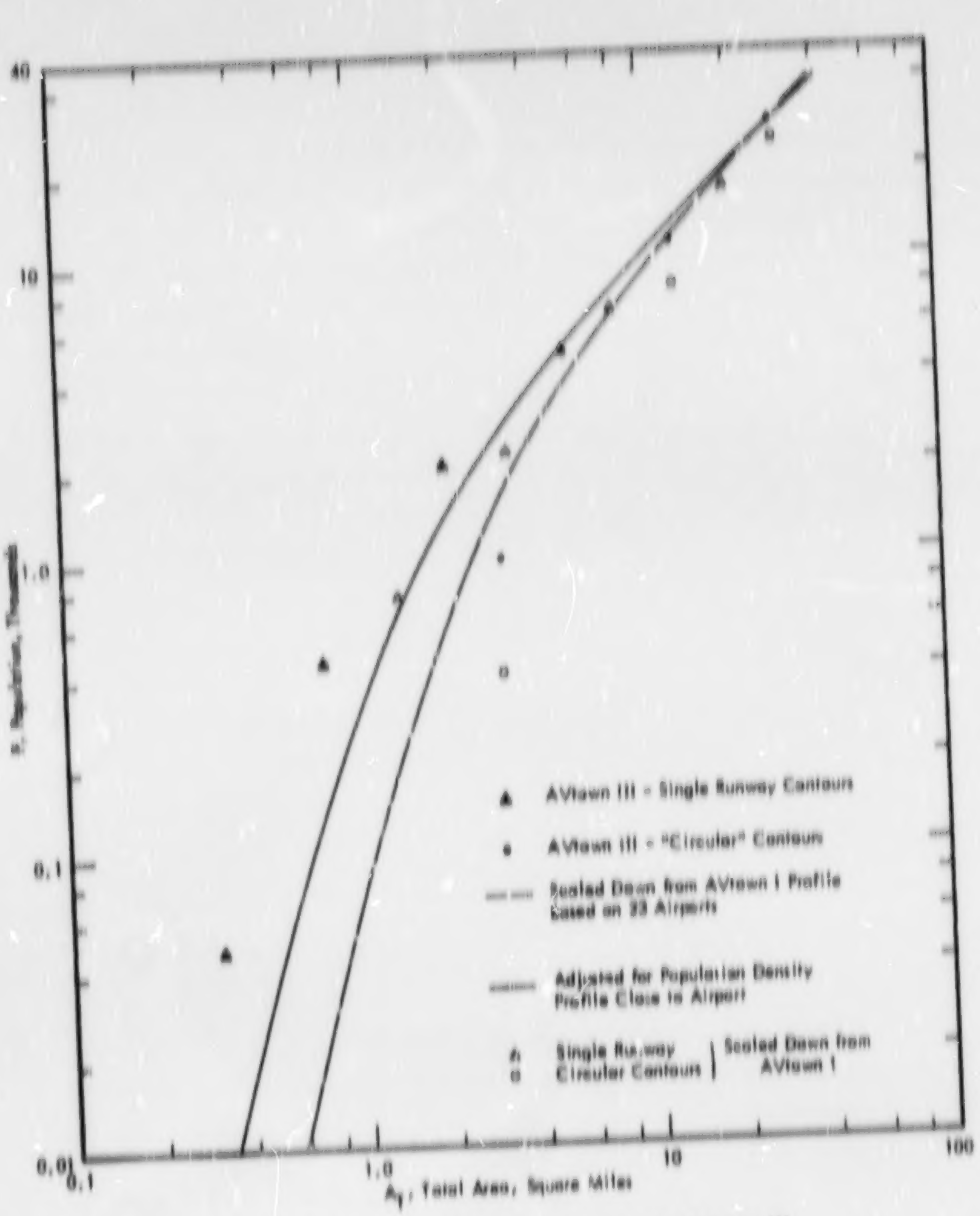

Figure 2-24. Population Versus Contour Area for AVtown III

Also shown for comparison are the circular and single runway data points for population versus contour area from the corresponding AVtowns. Finally, these same type of data points from AVtown I are shown scaled down by the same factor as for the dashed lines. In general, it seems clear that for the larger contour areas, the data points from the circular contours and the scaled line from AVtown I are in close agreement. The latter was then adjusted to lie closer to the single runway data points for small contour areas. This is consistent with the trends in population profile observed for the AVtowns.

The adjusted (solid) lines in Figures 2-23 and 2-24 were fitted to the same type of expression used for AVtown I to give the following equations.

$$P = 10^{\left[a_0 + a_1 x + a_2 x^2 + a_3 x^3\right]} \quad , \text{ 1000 people}$$

where

$$x = 10 \log_{10}[\,A_T \, , \, mi^2\,]$$

and for

AVtown II (10-39 Operations/Day)	AVtown III (Mid-Range) (40-99 Operations/Day)
$a_0 = -0.5997$	$a_0 = -0.5096$
$a_1 = 2.0627$	$a_1 = 2.4629$
$a_2 = -0.9654$	$a_2 = -1.3315$
$a_3 = 0.2322$	$a_3 = 0.3860$

These two expressions and the one specified previously for AVtown I constitute the basis for predicting the total population inside all of the AVport noise contours for 1972 conditions.

2.7.4 Projected Future Population

To provide some estimate of the impacted population for future years, the preceding expressions were effectively multiplied by 10 percent for 1981 and 20 percent for 1987. These increases in total noise-impacted population correspond approximately to the series D population projections by the Bureau of the Census.[39] No attempt was made to allow for any further encroachment of people around airports. That such a process has indeed taken place over the years can be inferred from Figure 2-19 by the rather dramatic profile of high population density in a zone centered around 2 to 7 miles from airports. The larger the airport and, in many cases, the older the airport, the higher the level of residential encroachment.

2.7.5 Ambient Noise Model

The ambient L_{dn} level is required for computation of Noise Units according to the method defined in Section 2.6.1. Ambient noise level in communities, excluding major concentrated sources such as airports or freeways, has been shown analytically[40] and experimentally[41] to be a function of population density. The following empirical relationship, developed experimentally in Reference 41, is used for this study.

$$L_{dn}(\text{Amb}) = 10 \log_{10}(\rho) + 22 \quad , \text{dB}$$

where

ρ = population density, people per square mile

This expression roughly predicted the ambient L_{dn} observed at 130 urban sites throughout the United States with a standard deviation of about 4 dB over a range of population density from 1000 to 70,000 people per square mile. However, this population density was the true density in occupied census tracts whereas the figures obtained from the AVtown census survey represent the average density in a given area including undeveloped land or uninhabitable areas, such as over water. Thus, the population densities (but not the total population figures) obtained from the AVtown data will tend to be lower than true values for occupied land only. The result is that predicted ambient noise levels will also tend to be lower than might be expected for current conditions. However, no attempt was made to correct for this situation for the following reasons.

- Ambient noise levels in the future are in fact expected to decrease as surface transportation noise control programs take effect.[5]
- By using a low estimate of ambient noise levels, the computed Noise Units will tend to be higher and hence more conservative. The change in Noise Units for a given change in aircraft noise level will also be maximized avoiding the tendency for NU to be less sensitive to changes in aircraft noise for high ambient noise levels (see knee of curve in Figure 2-12).
- Any possible correction to account for higher ambient noise levels was not well-defined for the smaller AVports.
- Finally, it has been shown in another recent study that relative ranking of noise reduction alternatives was not altered for major variations in noise weighting functions such as is employed in the Noise Unit Index.[42]

Thus, for this study, it was assumed that the population density to be used for computing ambient noise levels was equal to the total population or, more precisely, the incremental change in population between two contour values, divided by the corresponding incremental change in area. For example, if the total population inside an L_{dn} 65 contour was P_{65} and P_{70} inside the L_{dn} 70 contour and the corresponding total contour areas were A_{65} and A_{75}, the average population density for this noise zone was assumed to be

$$\rho = (P_{65} - P_{70})/(A_{65} - A_{70}) \qquad \text{, People Per Square Mile}$$

Based on the analysis of the area components — impacted land, water area, and airport property — inside NEF noise contours for the 23 airport study,[1] the contour area outside the airport boundary would consist on the average of 75 to 80 percent impacted land area.[7] However, some portion of this "impacted" land will be compatible non-residential (commercial, industrial, public, or undeveloped) property. To determine this value, the data for the population inside the NEF 30 contours for all 23 airports was reevaluated to determine what fraction of total contour area was actually populated. The result of this analysis is summarized in Table 2-18 which shows the absolute and percentage breakdown of contour area components for all 23 airports.*

Table 2-18

Breakdown of Land Use Inside NEF 30 Contour for All 23 Airports*

	Residential Land	Nonresidential Land	Water Area	Airport Property	Total
Area, Mi^2	363	525	360	85	1333
Percent	27.2	39.4	27.0	6.4	100

*Based on further breakdown of "impacted land" area identified in Reference 1 into populated and unpopulated (industrial, commercial, public, undeveloped) areas.

Thus, inside the NEF 30 (or approximately L_{dn} 65) contour for these airports, only 27 percent of the area is populated. Thus, population densities based on all the area inside a contour would be low by 1/.272 or 3.68 and corresponding ambient L_{dn} values would be low by 10 log(3.68) or 5.7 dB.

2.8 Noise Impact Analysis for All Air Carrier Airports

Having defined all the elements which go into computing noise environments and impacted population around the AVports, it now remains to define the method for scaling these figures to represent the aggregate for the nation's air carrier airports. The distribution of these airports, according to the number of daily operations, was shown earlier in Figure 2-2. By defining a relationship between number of operations and contour area, the desired scaling factors can be developed. That is, if one can relate contour area to operations, then by summing over all operations for airports in each AVport category, a scaling factor between the contour areas for the national aggregate and each AVport can be established.

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*For further details, see Table I-6 in Appendix I.

2.8.1 Contour Area Versus Daily Operations

Since the L_{dn} noise metric effectively counts the time-weighted noise energy at a given point, there is a systematic relationship between L_{dn} value and number of operations which can be expressed in a simplified form by:

$$L_{dn} = \overline{L_{NE}} + 10 \log(N_c) - 49.4 \quad , \text{dB}$$

where

$\overline{L_{NE}}$ = Energy Average Noise Exposure Level of all single events (i.e., aircraft flyovers during a 24-hour period)

N_c = weighted number of events equal to daytime events plus 10 times the nighttime events (or operations)

For a given mix of daily operations (N_c = constant), the value of L_{dn} increases directly as $\overline{L_{NE}}$ increases, which occurs as distance to the aircraft is reduced. Thus, L_{dn} contours decrease in area as the L_{dn} value increases. Now, for a constant L_{dn}, if the number of operations increase, the Average Noise Exposure Level ($\overline{L_{NE}}$) must decrease as the L_{dn} contour increases in area. Thus, all other things being the same, increasing the number of operations increases the area of a given L_{dn} (or NEF) contour. The net result of these trends is illustrated conceptually in Figure 2-25.

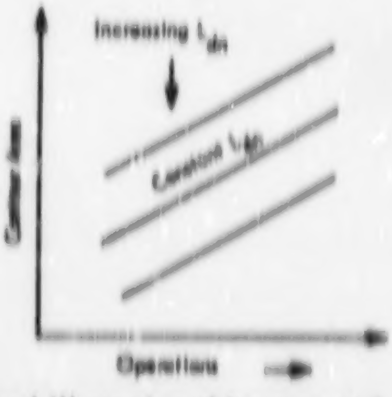

Figure 2-25. Conceptual Illustration of Increase in Contour Area for Increasing Number of Operations and Constant L_{dn} and Decrease in Contour Area for Increasing L_{dn} and Constant Number of Operations

To approximate the condition – "all other things being the same" – at all airports, it was assumed that the actual varying mix of aircraft types could be treated as essentially fixed by the simple rule of counting each jet aircraft operation, regardless of the aircraft type, as one full operation and counting each propeller aircraft operation as one-tenth of an operation to account, roughly, for its lower noise level. Thus, a weighted number of equivalent operations (N_e') at an airport was defined as:

$$N_e' = N_d(\text{jet}) + 10N_n(\text{jet}) + 0.1[N_d(\text{prop}) + 10 \cdot N_n(\text{prop})]$$

where N_d and N_n signify daytime and nighttime operations respectively.

Figure 2-26 shows how the total area (A_T) within the NEF 30 contours from the 23 airport study and the L_{dn} 65 contours for the three AVports in this study vary with this number of weighted equivalent daily operations (N_e').* Least squares regression lines through the two sets of data have the form $A_T = a(N_e')^b$. The exponent b is nearly unity in each case indicating almost a simple linear relationship. The NEF and L_{dn} regression lines are, in fact, very nearly the same. In any event, one element of the basic scaling concept is obtained – a simple relationship between contour area and equivalent operations for the L_{dn} 65 1972 baseline contours.

The same type of relationship is required for the other L_{dn} values and for the other years to cover all noise reduction alternatives. Figure 2-27 shows that the same regression line found for L_{dn} 65 for the 1972 baseline AVtown cases also applies to the higher L_{dn} values – only the magnitude of the area is changed by a vertical shift downward of the regression line as indicated by a decrease in the constant a. Note that the slope of the best-fit lines through the area versus operations data points varied by less than 1 percent so the average slope for the L_{dn} 65 data was used for all.

The same analysis was carried out for the baseline cases for the years 1981 and 1987 and the results are shown in Figures 2-28 and 2-29. Again, the slope of the best-fit lines for L_{dn} 65 to 85 varied only slightly so that a constant slope could be used for all. For these figures, there are more data points than for 1972 for each

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*For further details, see Table I-9, Appendix I.

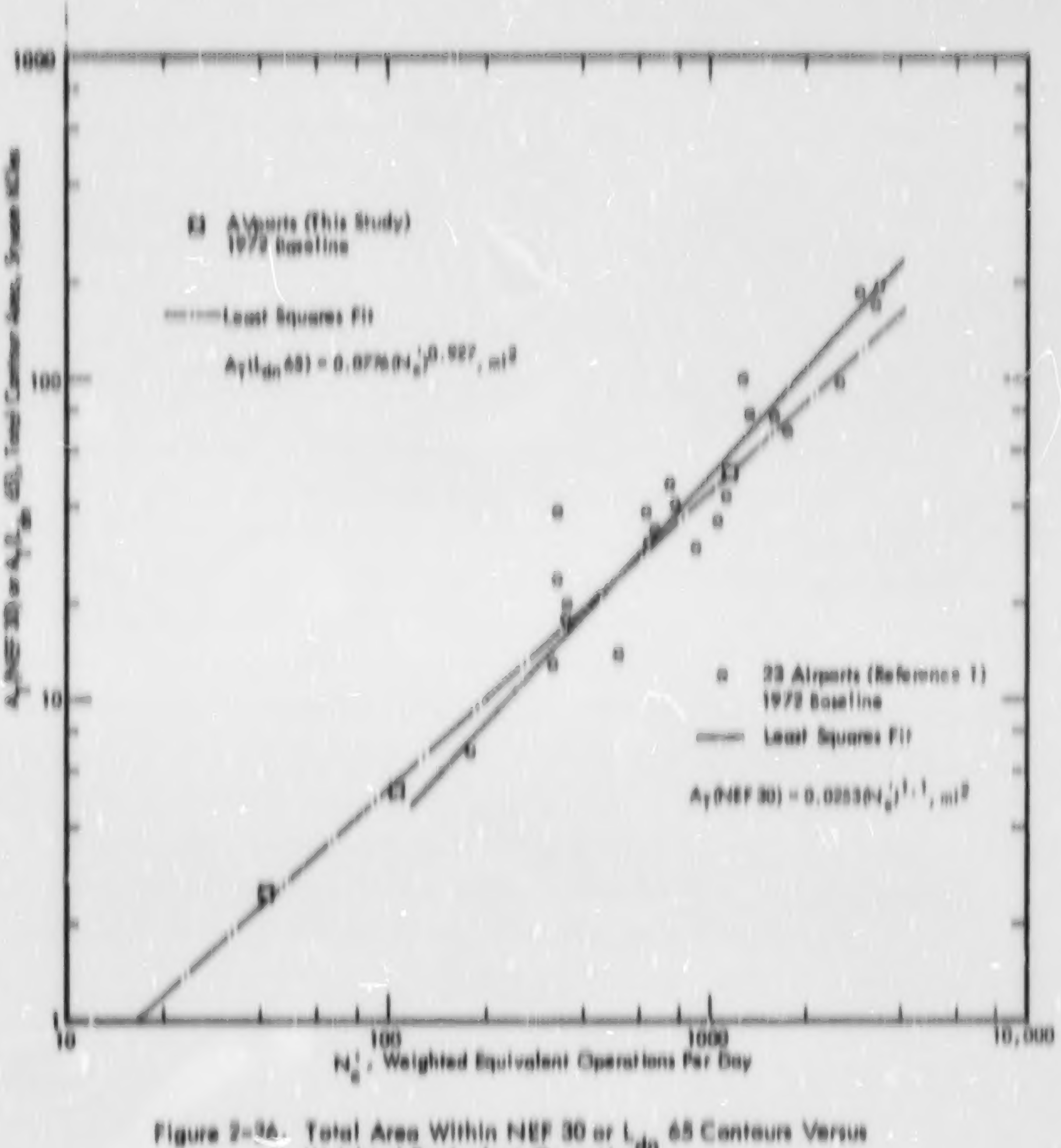


Figure 2-36. Total Area Within NEF 30 or L_{dn} 65 Contours Versus Weighted Equivalent Operations

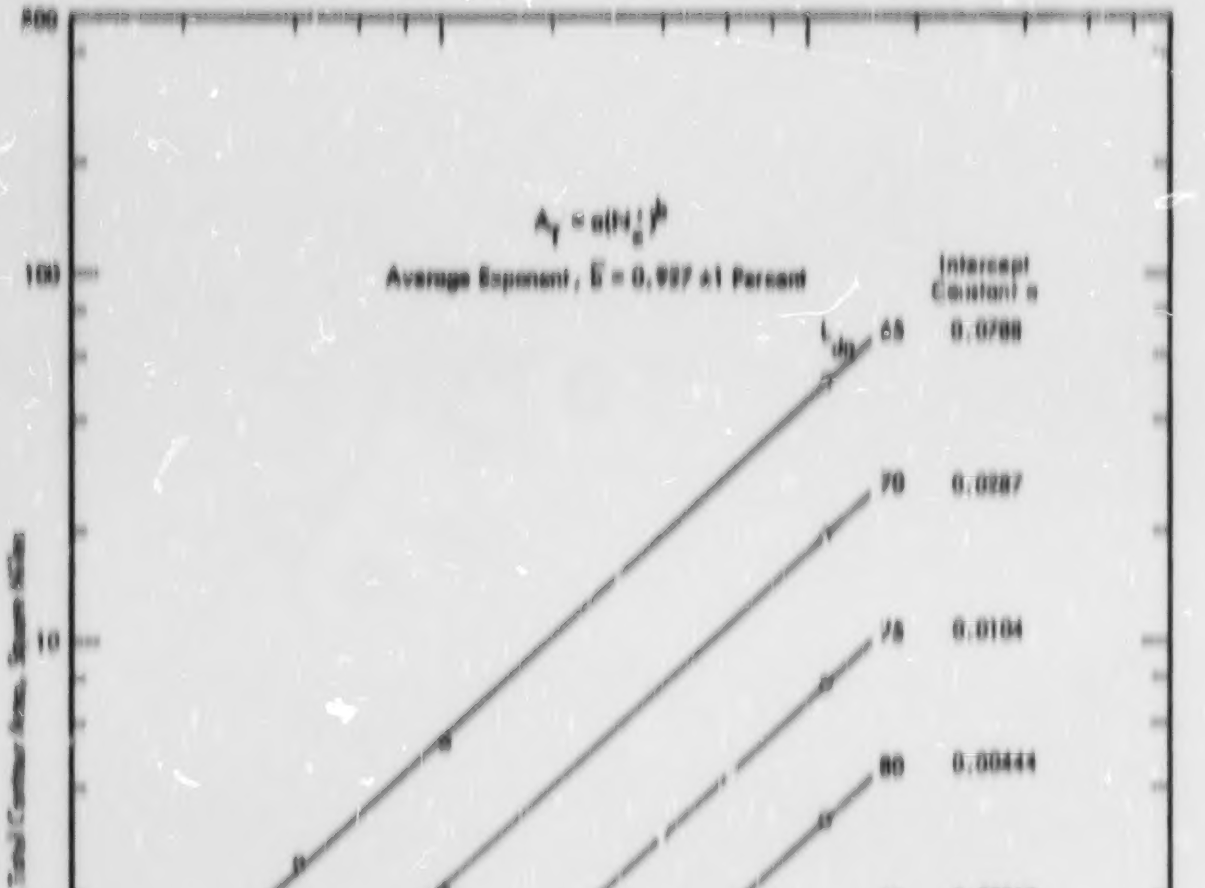


Figure 2-27. Total Contour Areas Versus Weighted Equivalent Operations - 1972 Base

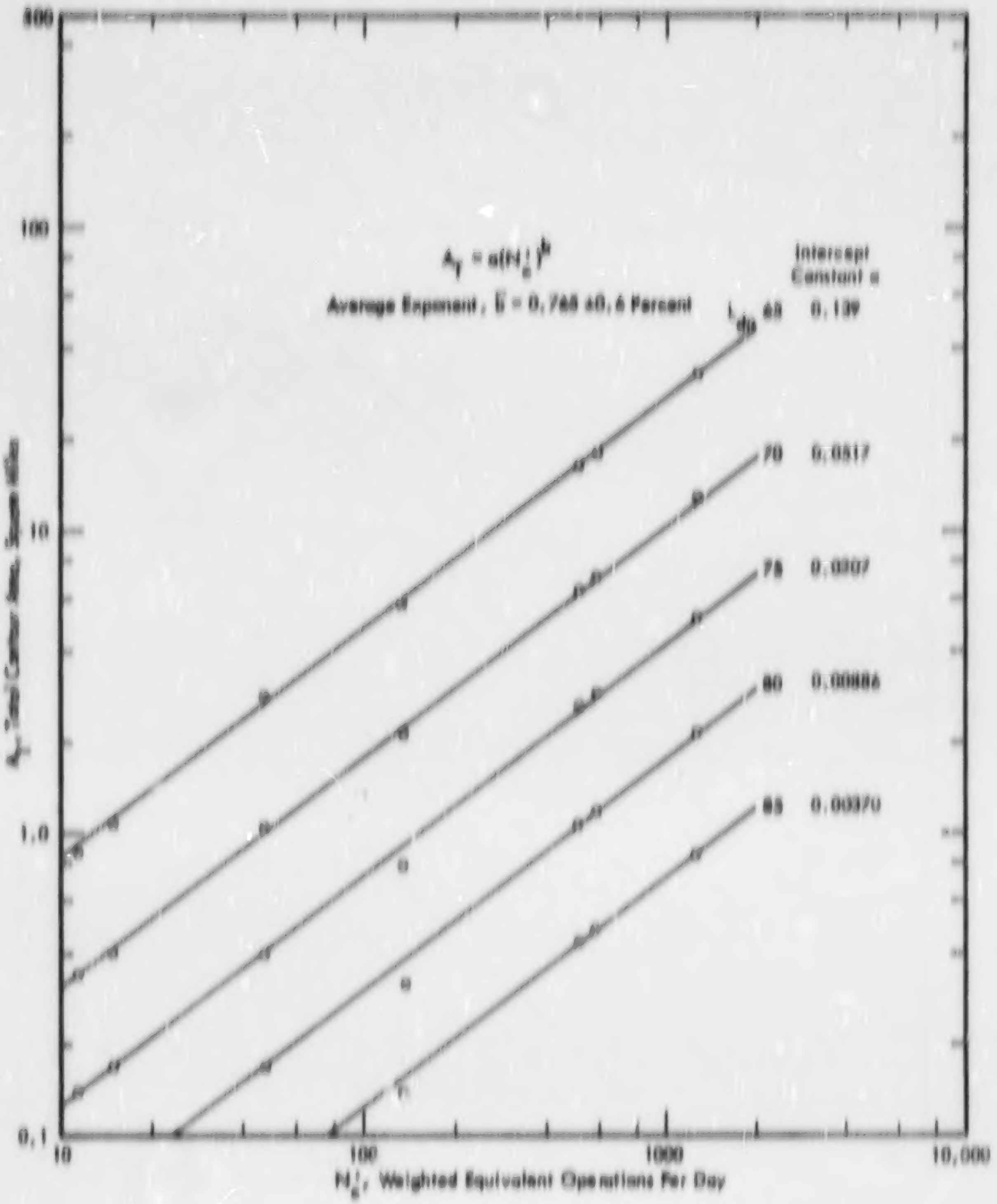


Figure 2-28. Total Contour Areas Versus Weighted Equivalent Operations - 1981 Base

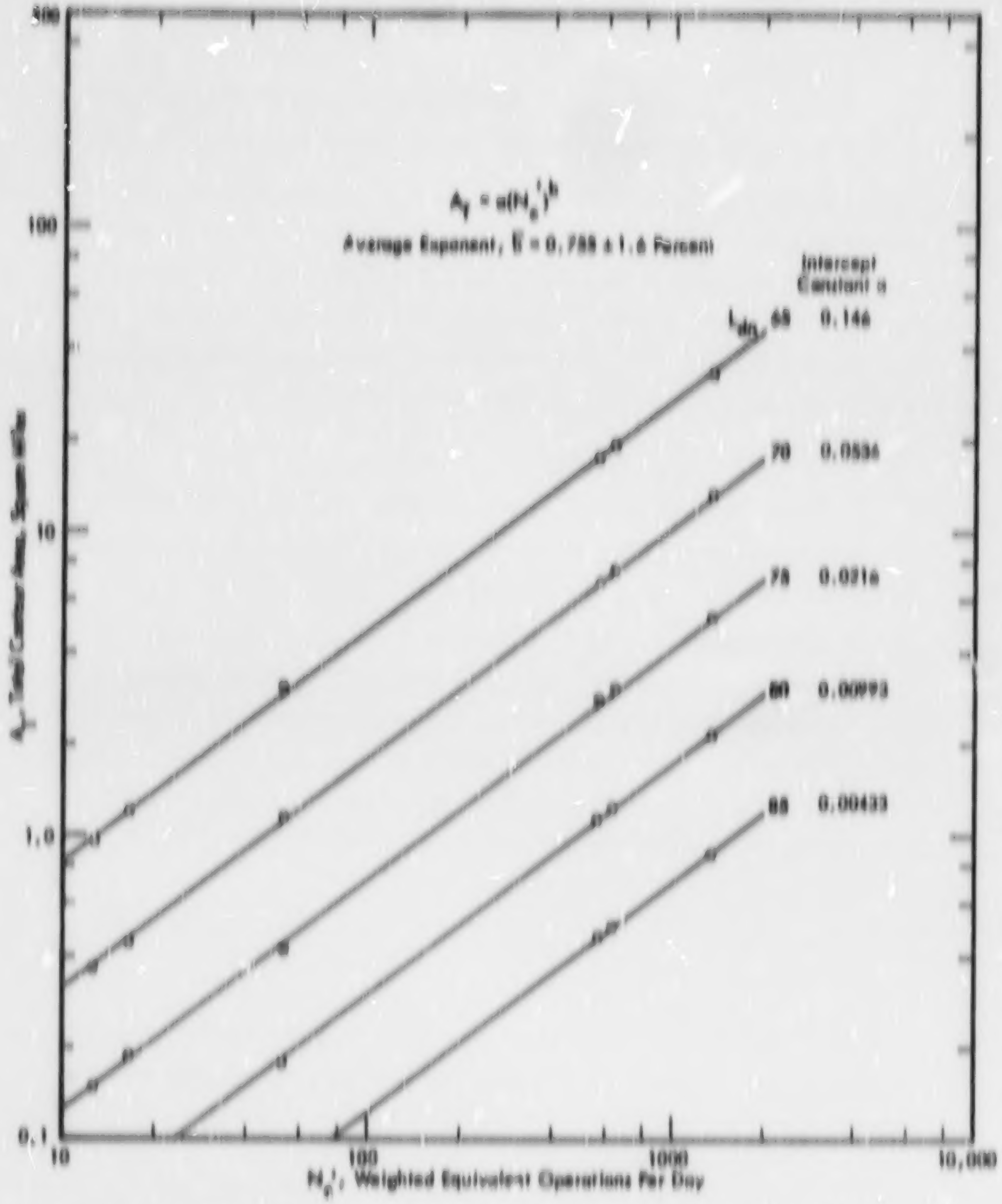


Figure 2-29. Total Contour Areas Versus Weighted Equivalent Operations - 1987 Base

L_{dn} reflecting the fact that the curfew cases for each year also can be used to determine different values for the equivalent number of operations.

A comparison of these last three figures illustrates one rather surprising point. A single consistent relationship can be drawn between contour area and the rather crude measure of equivalent operations within any one year even though there is a significant variation in the mix of aircraft types over this range of operations. However, between 1972 and 1981, the effective mix of aircraft types changed even more so that a new expression for area versus operations was required.

2.8.2 Scaling AVports to the Nation

Given the relationship between total contour area and operations outlined in the preceding section, a method for scaling from AVport contour areas to the nation is developed as follows.

Let the contour area for each airport in the i^{th} group with the same number of operations N_i be given by the symbol A_{Ti}, or dropping the subscript T, simply A_i. Let this area vary in a general way with N_i as the function $A(N_i)$. Then, for a population of airports expressed by the distribution $n(N_i)$, indicating n airports with N_i daily operations, the total contour area over the nation will be the sum ΣA_i over the i intervals of operations N_i of the contour area per airport $A(N_i)$ times the number of airports with this many operations, $n(N_i)$, or:

$$\sum A_i = \sum_i A(N_i) \cdot n(N_i) \quad , \text{mi}^2$$

Carrying out this summation over each of the AVport categories separately and then dividing the resulting sum by the area for the corresponding AVports provides the desired scaling factor. Thus, for the m^{th} AVport, the scale factor, $F_s(m)$, is

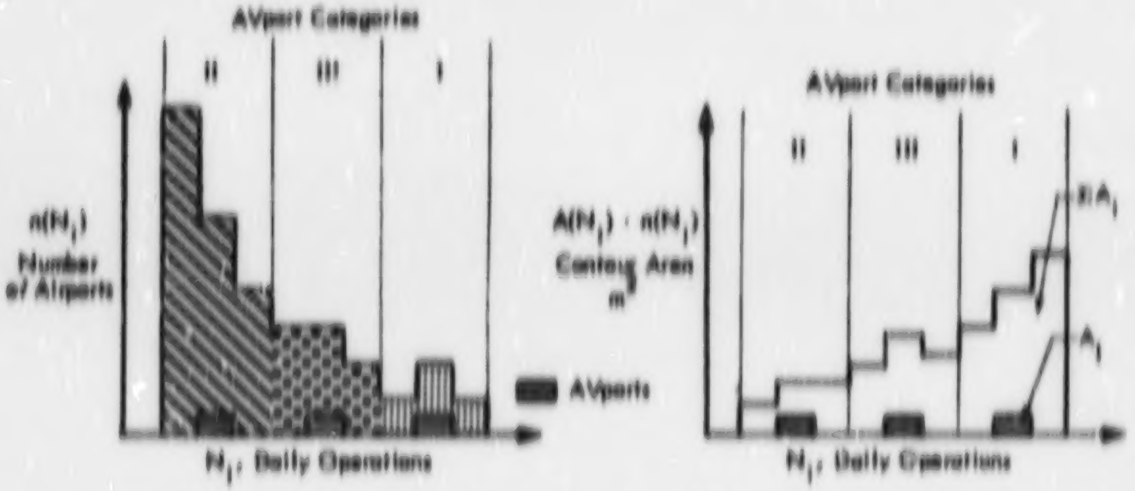
$$F_s(m) = \frac{\sum A_{im}}{A_m}$$

where

$\sum A_{lm}$ is the sum of the contour areas for all airports in AVport category m

and $m = I, II,$ or III for the corresponding AVports

Figure 2-30 illustrates this concept.



a) Number of Airports Versus Number of Operations

b) Aggregate Contour Area Versus Number of Operations

Figure 2-30. Illustration of Scaling Concept Between Contour Area A_i for i^{th} AVport Category and Aggregate Sum ΣA_i Over All Airports in the Same Category

The application of this scale factor will be as a multiplier for the computed AVport contour area to obtain the unknown total area ΣA_i. How then, do we find ΣA_i so that the scale factor can be computed from the preceding expression?

From the last section, the total contour area was related to the total equivalent operations N_e' by an equation of the form

$$A_T = a(N_e')^b$$

If we assume that the weighted equivalent operations N_e' is related to the actual operations N_i by a constant K so that

$$N_e' = K N_i$$

we can then write out the form for the general function $A(N_i)$ relating contour area and N_i operations as

$$A(N_i) = a(N_e')^b = a(K N_i)^b = a K^b N_i^b$$

Similarly, for the specific case of the m^{th} AVport, its contour area could be predicted by

$$A_m = a K^b N_m^b$$

where m = I, II, or III

Combining the above expressions provides the desired expression for the scaling factor for the m^{th} AVport as

$$F_s(m) = \frac{\sum A(N_i)_m \cdot n(N_i)_m}{A_m}$$

$$= \frac{\sum a K^b N_i^b \cdot n(N_i)_m}{a K^b N_m^b}$$

$$= \frac{\sum N_i^b \cdot n(N_i)_m}{N_m^b}$$

Thus, the scaling factor for the m^{th} AVport is equal to the weighted sum of the number of airports in each category, where the weighting factor is the quantity N_i^b, all divided by the corresponding weighting factor for this AVport, N_m^b. The key variable is simply the exponent b in the expression relating contour area and equivalent operations N_i. The other constants a and K cancel out. Since the exponent b varied for each year, the scaling factor changed accordingly.

The distribution $n(N_i)$ of airports versus operations for 1972 has been illustrated earlier in Figure 2-2. The distribution for future years was estimated as follows.

First, it was assumed that the basic shape of this distribution profile of number of airports versus operations would remain the same – only its position along the number of operations axis would change to reflect the change in total air carrier operations in future years. This is a reasonable assumption according to a previous detailed evaluation[7] of FAA's projected airport operations profiles.[8] For example, given 11 air carrier airports in 1972 with operations of 100 to 125 per day, a 10 percent increase in all operations would amount to saying that these same 11 airports now had 110 to 137 operations a day. This neglects any possible change in the total number of airports but provides a reasonable and simple method for forecasting airport profiles for this study.

The change in the total number of air carrier operations in future years was covered earlier in Section 2.4.2 (see Table 2-7 for final results). The resulting estimate of the increase in total number of air carrier operations was:

1972 to 1981 = Increase by 14.2 Percent
1972 to 1987 = Increase by 10.7 Percent

These factors were therefore applied to the 1972 airport population profile $n(N_i)$, illustrated in Figure 2-2, to obtain estimated profiles of $n(N_i)$ for these future years. In carrying out the computations with these airport population profiles, geometric mean values of the operations N_i for each interval were used. It will be recalled that the operations intervals for these profiles differed by a constant ratio equal to the one-tenth power of 10 or 1.26, thus assuring that the profile was divided into fine steps for accurate computations.

Based on the methods and data outlined above, appropriate contour area scaling factors were computed for each of the AVports. Tables 2-19 to 2-21 present the data used in these calculations for each year and the final values are listed below:

Table 2-22

Summary of Scaling Factors (F_s) for Total Areas of L_{dn} Contours for Each AVport

Year		1972	1981	1987
AVport	I	40.9	41.3	40.2
AVport	III	52.8	49.3	(46.1)[a]
AVport	II	147.4	142.6	126.0

[a] Estimated as 93.5 percent of scale factor for 1981.

2.8.3 National Values for Noise Impact at Air Carrier Airports

Impact Area

The contour areas for each AVport, year, and noise reduction alternative listed in Table E-1 in Appendix E were multiplied by the corresponding scale factors from the table above to produce the areas for all air carrier airports in each AVport category. (The AVport III areas not given in Table E-1(c) were computed in Appendix F.) The resulting areas are given in Table E-2 in Appendix E. The sum of these areas, encompassing essentially all air carrier airports in the nation, is given in Table 2-23 for each aeronautical and operation noise reduction alternative.

Impacted Population

The expressions for population inside the L_{dn} contours as a function of total contour area, derived in Section 2.7, were used to determine the impacted population around all airports in corresponding AVtown categories. The contour areas were

Table 2-19

Computation of Contour Area Scaling Factors (F_s) for Each Airport — 1972

[illegible]

Table 2-20

Computation of Contour Area Scaling Factors (F_s) for Each Airport — 1981

Nominal Ops/Day[1]			Actual N_i[1]	No. Airports	Cum. Ops.	Airport	b[2]	$N_i^b \cdot n(N_i)$	Cum.	N_m^b	F_s
i	Min.	Max.	Ops/Day	$n(N_i)$	$\sum N_i \cdot n(N_i)$	N_m			$\sum N_i^b \cdot n(N_i)$		
1	1428	1807	1808		1			311.6			
2	1142	1428	1238		2			482.2			
3	914	1142	998		1			196.9			
4	719	914	845		4			893.6			
5	571	719	624		5			695.9			
6	457	571	507		3			370.0			
7	360	457	405		3	= 23,092	500	0.765	296.4	5602.3	116.1	48.3 I
8	286	360	327		7			987.1			
9	228	286	254		8			953.1			
10	180	228	194		6			537.5			
11	143	180	166		9			449.4			
12	114	143	128		11			455.6			
13	91.4	114	90.5	14				472.6			
14	71.9	91.4	70.9	17				313.9			
15	57.1	71.9	63.3	22	= 4,039	94.0	0.765	477.6	1464.7	32.3	45.3 III
16	45.7	57.1	50.2	10				288.0			
17	36	45.7	40	28				470.7			
18	28.6	36	32.3	29				415.9			
19	22.8	28.6	25.9	16				192.3			
20	18.3	22.8	20.1	14	= 3,521	24.0	0.765	139.8	1625.1	11.4	142.6 II
21	14.3	18.3	16.2	24				202.1			
22	11.4	14.3	12.9	29				255.1			
	< 11.4		2.78	259	= 698			552.7			
	TOTAL			514	31,288						

(1) $N_i = N_i$ (1972) × 1.142

(2) See Figure 2-31.

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Table 2-21

Computation of Contour Area Scaling Factors (F_s) for Each Airport – 1987

	Nominal Ops/Day(1)		Actual $N_i^{(1)}$	No. Airports	Cum. Ops.	Airport			Cum.		
i	Min.	Max.	Ops/Day	$n(N_i)$	$\sum N_i \cdot n(N_i)$	N_m	$b^{(2)}$	$N_i^b \cdot n(N_i)$	$\sum N_i^b \cdot n(N_i)$	N_m^b	F_s
1	1384	1771	1782	1	≈22,385	439	0.755	283.3	5072.9	129.3	40.2 I
2	1107	1384	1192	2				422.4			
3	886	1107	965	1				179.6			
4	697	886	819	4				633.3			
5	554	697	614	5				626.9			
6	443	554	500	3				441.9			
7	349	443	393	3				272.8			
8	277	349	317	7				541.2			
9	221	277	246	8				500.8			
10	177	221	198	6				302.7			
11	138	177	161	9				407.2			
12	111	138	126	11				423.8			
13	88.6	111	96.4	14	≈3,915	69.3	0.755	443.7	1389.6	24.71	56.1 II
14	69.7	88.6	77.5	11				293.6			
15	55.4	69.7	61.3	20				447.3			
16	44.3	55.4	49.7	13				188.8			
17	34.9	44.3	38.7	28	≈3,413	26.94	0.755	442.5	1535.6	12.0	128.0 III
18	27.7	34.9	31.5	29				392.3			
19	22.1	27.7	25.0	16				181.8			
20	17.7	22.1	19.5	14				131.9			
21	13.8	17.7	15.7	26				191.9			
22	11.1	13.8	12.5	29				195.2			
	<11.1		2.61	239	676			534.4			
	TOTAL			514	31,239						

(1) $N_i = N_i$ (1972) × 1.387

(2) See Figure 2-25.

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Table 2-23

Area Within L_{dn} Contours –
National Composite for all Air Carrier Airports
Area in Square Miles

		Contour Level (L_{dn})				
Year	Alternative	65	70	75	80	85
1972	Base	2741,0	1030	403,3	172,3	73,6
1981	Base	2046,2	788,6	306,9	128,0	52,0
1981	Power Cutback	2116,2	693,8	283,8	125,5	52,0
1981	4° Approach	1963,9	710,0	283,8	122,6	49,7
1981	SAM 8D/3D	1715,0	675,2	267,5	112,7	46,1
1981	6°/3° Approach	1906,0	733,8	295,6	128,4	52,0
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	1355,5	530,7	256,3	114,3	46,6
1981	Curfew – Night Flights Rescheduled to Day	1031,5	397,3	163,3	66,4	27,5
1981	Curfew – Night Flights Eliminated	905,9	352,8	145,4	59,5	25,8
1987	Base	2034,8	786,3	303,8	126,0	52,2
1987	Power Cutback	2230,9	679,0	277,5	123,0	52,2
1987	4° Approach	1955,4	713,3	281,2	119,6	50,4
1987	SAM 8D/3D	1712,9	672,1	266,0	111,8	46,9
1987	6°/3° Approach	1891,4	731,5	292,0	126,0	52,2
1987	6°/3° Approach, Power Cutback, SAM 8D/3D FAR 36-10 (Since 1981)	1212,9	440,6	223,2	99,8	40,3
1987	Curfew – Night Flights Rescheduled to Day	1060,8	409,3	167,8	68,8	29,4
1987	Curfew – Night Flights Eliminated	940,2	365,5	149,6	62,3	25,9
1987	FAR 36-10 (Since 1981)	1856,1	695,9	276,6	111,0	47,0

obtained, as before, from Table E-1 and the resulting values of population per AVport multiplied by the same scaling factors listed in Table 2-22 except that the scale factors for 1981 and 1987 were increased by 10 percent and 20 percent respectively to allow for the future population growth (see Section 2.7.4). The resulting values of population for all airports in each AVtown category are given in Table E-3 in Appendix E. The total impacted population for the aeronautical and operational alternatives for all airports is given in Table 2-24.

For the residential noise reduction alternatives, the impacted population at each 5 dB increment of noise reduction is defined by shifting the baseline population down by the corresponding 5 dB increment. For example, if 124,000 people reside within the L_{dn} 80 to 85 dB band for the 1972 baseline case, then the population within the L_{dn} 75 to 80, 70 to 75, or 65 to 70 dB bands will also be 124,000 for 5, 10, or 15 dB, respectively, of residential noise reduction.

The number of households in each noise band, which is required to cost out the receiver noise abatement alternatives, is determined by evaluation of average household size from a detailed analysis of census data for three out of the 23 airports – Seattle, Minneapolis, and Atlanta. This process is discussed in more detail in the next chapter and in Appendix G.

Noise Units

Noise Units (or Equivalent Noise Impact) were computed with the data in Tables 2-23 and 2-24 in the following way. The increments in population (ΔP) and area (ΔA) between each contour level were determined to define the effective population density $\rho = \Delta P/\Delta A$ for each L_{dn} interval (i.e., 65-70, 70-75, 75-80, 80-85, and > 85 dB). This population density was then used to define the ambient noise level as explained in Section 2.7.5. The geometric mean L_{dn} level in each L_{dn} band

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[*] A calculation of Noise Units, based on using the area and population values for each AVtown category in Tables E-2 and E-3, produced values very nearly the same as those based on the national figures.

Table 2-24

Population Within L_{dn} Contours -

National Composite for all Air Carrier Airports

Population (000)

Year	Alternative	Contour Level (L_{dn}) 65	70	75	80	85
1972	Base	7089,5	2070,2	616,3	139,2	15,0
1981	Base	4654,4	1475,4	372,6	57,9	3,0
1981	Power Cutback	4979,4	1179,9	306,7	53,8	3,0
1981	4° Approach	4473,5	1274,9	319,7	49,9	2,4
1981	SAM 8D/3D	3667,1	1164,1	277,4	38,8	1,5
1981	6°/3° Approach	4177,6	1307,5	342,4	58,6	3,0
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	2551,8	711,8	238,2	38,4	1,5
1981	Curfew - Night Flights Rescheduled to Day	2174,9	614,5	120,8	10,0	0,20
1981	Curfew - Night Flights Eliminated	1892,9	522,2	76,5	7,1	2,0
1987	Base	5104,9	1622,4	413,8	65,4	3,5
1987	Power Cutback	5478,3	1276,2	336,6	60,2	3,5
1987	4° Approach	4914,0	1424,0	335,5	57,1	2,9
1987	SAM 8D/3D	4060,7	1296,8	313,6	44,9	1,9
1987	6°/3° Approach	4581,9	1441,4	378,8	65,4	3,5
1987	6°/3° Approach, Power Cutback, SAM 8D/3D FAR 36-10 (Since 1981)	2591,9	685,7	241,0	39,6	1,6
1987	Curfew - Night Flights Rescheduled to Day	2491,5	722,4	146,6	13,2	0,3
1937	Curfew - Night Flights Eliminated	2199,3	622,8	120,3	9,7	0,2
1987	FAR 36-10 (Since 1981)	4762,9	1459,2	378,4	81,4	2,9

(68.2 dB for the 65 to 70 dB band) was taken as the corresponding aircraft noise level. The aircraft and ambient levels were then added, on an energy basis, to determine the total noise level. The fractional impact and Noise Units were then calculated as outlined in Section 2.6.1. The values of total contour area, impacted population and Noise Units for all the alternatives are presented in Section 4 in summary tables.

2.8.4 Influence of Freeway Noise in Airport Noise Impact

There was one additional factor considered in the evaluation of Noise Units. This was the ability of noise from freeways near an airport to significantly increase the ambient noise level above that based on only the average population density. The net results could be a significant change in the Noise Units. To investigate this effect, a detailed reevaluation of noise environments was made of three of the airports from the 23 airport study (Atlanta, Minneapolis, and Seattle). This analysis consisted of computing the ambient and aircraft L_{dn} values at fixed grid locations spaced at 2000 ft by 2000 ft cells. The ambient noise level was computed from the population density based on the total population for all census population centroids within each 2000 ft by 2000 ft cell.

A rough approximation of the effect of freeway noise was included by adding 5 dB to the ambient L_{dn} in any cell which was traversed by a freeway. Then, this correction was dropped and the analysis repeated. Table 2-25 indicates the increase in the energy average ambient L_{dn} and corresponding decrease in Noise Units for each aircraft L_{dn} band for the 1972 base case. The energy average ambient L_{dn} was simply the average on an energy basis, of the ambient L_{dn} values in each populated 2000 foot by 2000 foot cell that fell within each L_{dn} band interval.

The average ambient level increased by 1.2 dB ± 1.2 dB over all L_{dn} bands for the three cities and the corresponding decrease in Noise Units was -6.4 percent ± 6.4 percent. While this freeway noise effect is not negligible, it was considered too small and too variable to justify further evaluation in this study. More important, it is not expected that the rank order of the cost-effectiveness of any of the noise reduction alternatives considered would be influenced by this freeway noise effect.

Table 2-25

Change in Average Ambient Noise Level, ΔL_{dn}(Amb) and Noise Units (ΔNU) at Three Airports Due to Approximate Correction for Freeway Noise

Airport		L_{dn} Band				
		65-70	70-75	75-80	80-85	> 85
Atlanta	ΔL_{dn}(Amb) dB	0.5	0.6	0.9	1.3	3.7
Minneapolis		1.8	1.5	3.1	*	*
Seattle		1.7	0.5	0	0	0
Average		1.2 ± 1.2 dB				
Atlanta	ΔNU %	-3.1	-2.9	-3.4	-4.2	-13.4
Minneapolis		-13.6	-8.9	-19.8	*	*
Seattle		-11.6	-2.6	0	0	0
Average		-6.4 ± 6.4%				

*No populated cells in this L_{dn} band.

2.8.5 National Values for Noise Impact at General Aviation Airports

An analysis was made of the noise impact around more than 6600 general aviation airports in the U.S. The procedures used in this analysis are summarized in Appendix H. They were patterned after those followed for the air carrier airports but required a number of additional steps with regard to the mix and operations of the general aviation fleet. The results of this analysis, which provided estimates of the total area impacted and the Noise Units, are treated at the end of Chapter 4.

3.0 COST ANALYSIS

3.1 Introduction

In Section 2, it was clearly shown that airports typically develop a high density land use pattern close to the airport. It is desirable, therefore, to summarize recent legal trends affecting property rights of land owners near airports. The following section, 3.2, discusses these issues and highlights optional uses, should a land acquisition policy be pursued to reduce the impact of noise on the population near airports.

With this as background, the cost analysis of feasible abatement measures is developed in this chapter in three steps. First a detailed examination of three airports, (Atlanta, Minneapolis, and Seattle), is undertaken to identify specific relationships which might otherwise be difficult to observe in the aggregate data. For each airport, the costs of noise reduction treatment and relocation which can be expected if the maximum noise exposure of residents is to be reduced are developed. Certain relationships between household size, proximity to airport and land values are developed and utilized for subsequent analyses.

The second step is the assessment of similar costs for the composite AVtown model utilizing the data building blocks developed for the three airports.

Third, national population estimates of airport surroundings are used as a basis for developing the implementation costs of selected abatement measures on the ground as well as at the source. All estimates (data building blocks, three airports, as well as the national profile) are developed in 1975 dollars.

A separate analysis in Section 3.5 develops costs of abatement measures at the source – the SAM, REFAN, and 6°/3° glide slope options are stipulated and the cost impact of each option on the projected fleet is computed. In view of prevailing interest, this section also includes a qualitative assessment of these abatement measures on expected aircraft fuel consumption problems.

3.2 Land Use Implications

In assessing the effect of aircraft noise on the value of real estate, impacts can be measured by changes in the price (market value) of property or by the cost of countermeasures needed to prevent or compensate for the effect of aircraft noise. The mere fact that a property is located near a noise source is not prima facie evidence of loss in value. The offsetting factor of large demand for property with ready airport access will often hide the depressing effect of aircraft noise.

Property owner concerns are frequently governed more by fear of economic loss than by fear of impaired health and safety. This is exemplified by accounts of experience in the Westchester area of Los Angeles which is exposed to significant noise from the nearby airport. The real estate office of the Los Angeles Department of Airports indicated that the individuals who sold their homes to the airport often stayed on as tenants. This may indicate that the homeowners did not fear the aircraft noise, but the possible diminution in the value of their property. Once their original investment had been recovered, they were willing to live with the noise.

In addition to the above complications, the consumer does not have access to perfect information, thus making it questionable as to what inferences can be drawn from market value studies.

The following comment illustrates the difficulties:

> It is unlikely that property values reflect *all* of the benefits of pollution abatement. In the opinion of most urban or environmental economists, the real estate market reflects the more tangible aspects of pollution -- more rapid deterioration of materials; extra cleaning and maintenance costs; the nuisance caused by smells, dirt and noise; and the milder medical symptoms such as shortage of breath and smarting eyes. The subtle, more insidious long-term health effects of pollution are likely to escape consumer notice and will *not* be reflected in market values. As a consequence, property damage estimates must be supplemented with additional damage information drawn from so-called "technical coefficient studies."[43]

Externalities. In the case of aircraft noise, we are dealing with technological external diseconomies which means that the producer of the noise does not have to bear all of the costs that aircraft noise imposes on other members of society. The need for governmental action arises if there is no market mechanism to ensure that the damaged party receives compensation from the party that creates the costs. Such intervention can take many forms, but particularly relevant is judicial action.[44-46]

The main issue addressed by judicial action in the case of aircraft noise is invasion of air space. Two theories have been applied to the problem -- one property taking, one tort (i.e., nuisance).

Taking theory: If the noise of airplanes flying over land damages the owner in the use of the land, there may be inverse condemnation or a "taking" of property for which compensation must be paid. The amount is equal to the difference in value of land subject to the flight easement and value of land without the flight easement. This theory can be applied only to governmental units with power of eminent domain (the city or airport commission could be sued, but not airlines).

Nuisance theory: If noise pollution from airplanes is classified as a "nuisance," the landowner can collect damages.

Under the "taking" theory, the government would acquire an easement for a one-time payment. Under the nuisance theory, every repetition of the wrong may create further liability. If the "taking" theory requires the taking of an easement for flying over the land, it probably cannot be used to compensate owners who suffer noise pollution but whose airspace is not entered physically. However, limiting damages to only those owners exposed to direct overflights is apparently no longer a constraint if the nuisance theory is followed.

Recently in Los Angeles, Superior Court Judge Bernard S. Jefferson made a precedent-setting decision regarding damages for emotional and mental distress in an airport noise nuisance case. He ruled that injured families can sue repeatedly for damages for continuing emotional and mental distress. The judge suggested that Los Angeles could reduce future liability by one of three ways: (1) lower jet aircraft noise level, (2) buy affected homes from families through normal purchase negotiations or condemnation action, or (3) treat the homes with noise insulation.

Effects on property values. Recent studies using market surveys, noise insulation costs, easement costs, and litigation data indicate that residential property exposed to aircraft noise is worth 5 - 20 percent less than it would be if not exposed to aircraft noise.[43] The percentage depreciation depends on factors such as climate, value of houses, and level of noise experienced.

Some additional relevant findings of these studies are the following:

- Elasticity of demand for residential quiet has a value of approximately two, indicating that it is a *luxury good*. In other words, the change in demand for a home in a quiet residential neighborhood increases more rapidly than the change in personal income of the residents.
- Absence of aircraft noise is not an omnipresent public good. However, individuals have the option of buying the luxury good, "freedom from aircraft noise."

Implications for solutions. It appears intuitively that noise insulation might be among the most efficient solutions, because it makes use of the fixed investment in the existing housing stock. It seems extremely inefficient to acquire a house through eminent domain proceedings for $50,000 and then demolish it for an additional $500 when an investment for noise insulation of less than $15,000 per house can usually eliminate the problem. This issue is particularly acute if a housing shortage is considered to exist currently in the U.S.

If it is assumed desirable to reduce the number of persons subjected to excessive noise levels at various points surrounding airports, then an obvious alternative is to decrease the density of such areas by relocating residents to other areas. The financial ramifications of such action are extensive. In addition to relocation costs, there will be administrative costs incurred in acquiring the land for public use. The City of Los Angeles, for example, has spent over $124 million to acquire 2673 homes ($46,717 per home) since 1972 in order in remove residents from excessive noise near Los Angeles International Airport. By the time the acquisition program is complete, a total of over $135 million will have been spent.

A final question is what to do with the land in residential use surrounding airports if acquired or rezoned by government bodies. Although noise may adversely impact upon property values, high density commercial uses near airports usually result in increased demand for land and increased property values.

There are numerous possible solutions: (1) use as buffer zone, (2) exclusive agricultural use, (3) parking, (4) open space, (5) industrial use, (6) cemeteries, (7) light outdoor recreation, etc. However, two kinds of solutions not immediately obvious are "restricted use" zoning and transfer of development rights.

One example of a simple restricted land use zoning plan, developed by the Minnesota State Aeronautics Department primarily for safety considerations, could be adopted for noise to any airport.[47] The dimensions of the zones, identified as zones A, B, and C, extend to three times the maximum contemplated length of the runway (beyond the end of primary surface). Zone A would be restricted to uses which by their nature do not bring together an assembly of persons. Zone B would be less stringent but would still prohibit such uses as churches, hospitals, schools, theaters, stadiums, hotels, motels, trailer courts, etc. Zone C would have height restrictions and would prohibit any use which would affect landing safety (radio interference, glaring lights, etc.).

Transfer of development rights (TDR) is a new concept which may be well suited for the problems at hand.[48] The essence of the concept is as follows: A municipality designates areas where it desires no further development and prohibits development in those areas. Residential development potential in those areas is then transferred to other districts whose citizens agree development is feasible. This preserves environmentally important areas with equitable compensation for owners.

If utilized properly, TDR could make it unnecessary for the government to purchase additional land around airports. Existing residential areas could be downzoned to less dense uses (agriculture, parking, etc.), with an interim period established in which all owners would be required to conform to the new zoning regulations. At the same time, development rights would be created for existing owners. With proper planning, the value of these development rights could approximate the current market value of existing houses. As a result, (1) private funds would finance the transformation of residential areas to other uses, and (2) local real estate markets would receive a significant stimulus on several fronts.

3.3 Data Sources

This section will introduce and develop key cost and population data which comprise the foundation for conclusions in subsequent sections of the study.

Noise Insulation Costs serve as an index of the expenditure needed to permit the market value of real estate to fluctuate as if there were no aircraft noise penetrating the structures.

Past studies have made varying assumptions regarding what size constitutes an "average" house. General concensus is that two people require a house with a minimum of 1100 square feet of living area. Households studied in the vicinity of Atlanta, Minneapolis, and Seattle airports average 3.18 persons. A house of 1500 square feet is typical for such a household and this size will be utilized in the estimation of noise insulation costs.

Although "theoretical" studies of noise insulation costs were available, an earlier Wyle study (Reference 28) involving actual noise insulation treatment for 20 homes was used to determine noise insulation costs for the residential noise reduction alternative. The results of this study can be readily adapted to the present analysis, as incremental costs were calculated for varying levels of noise reduction. Table 3-1 summarizes the costs applicable to this study. These costs have been adjusted for inflation since 1969 and are expressed in 1975 dollars.[49] The costs additionally

	Noise Level Reduction		
	5 dB	10 dB	15 dB
Los Angeles (1969 Wyle data updated to 1975)	$ 2.60	$ 7.42	$13.47
Atlanta	$ 2.75 ($4125)	$ 7.82 ($11,730)	$14.21 ($21,315)
Minneapolis	$ 2.67 ($4005)	$ 7.62 ($11,430)	$13.85 ($20,775)
Seattle	$ 2.57 ($3855)	$ 7.36 ($11,040)	$13.34 ($20,010)
Average of Three Cities	$ 2.66 ($3990)	$ 7.60 ($11,400)	$13.80 ($20,700)
U.S. Average	$ 2.66 ($3990)	$ 7.62 ($11,430)	$13.86 ($20,790)

Table 3-1. Noise Insulation Costs (Per Square Foot). Figures in ( ) Are Total Costs for 1500 Square Foot House (1975 Dollars)

Costs are adjusted both for inflation and regional differences. Base for costs: 1969 Wyle Laboratories study in Los Angeles (Reference 28). Costs at that time were $1.64, $4.68, and $8.50 per square foot for reductions in A-weighted noise levels of 5 dB, 10 dB, and 15 dB respectively.

reflect regional differences in inflation rates and construction costs based on a cursory survey of 1975 material and labor costs.[50] Totals in the "U.S. average" row indicate that for the typical house exposed to aircraft noise, it would require an expenditure of $20,790 to reduce the noise level by 15 decibels. For each given location or average, costs are also listed for 5 dB and 10 dB reductions.

Noise insulation might also be expected to reduce energy consumption through a reduction in inefficient transfer of hot and cold air. However, the general dollar impact of this energy conservation cannot be estimated without extensive additional analysis to evaluate the energy gains resulting from the noise insulation treatment and potential energy losses due to the addition of an air circulation system frequently required.

The L_{dn} noise band described as ≥ 85 dB is assumed to exhibit an average noise level of 90 dB. This assumption is necessary when calculating noise insulation costs for a given maximum noise level goal. For example, if it is desired that housing units experience a maximum noise level of 80 dB, under this assumption it would be necessary to install sufficient noise insulation in the ≥ 85 dB band housing units to reduce the noise level by 10 dB. Unless otherwise specified, all costs are in terms of 1975 constant dollars.

Relocation costs. In terms of relocation assistance, it is desirable to require payment of actual and reasonable moving expenses when property is acquired for public use. For the standard house of 1500 square feet, these expenses would typically range from $400 to $700 for moving and packing, assuming reimbursement would be given only for a local move of 50 miles or less. An average cost of $550 will be utilized in determining overall relocation costs.

Cost of real estate as measured by values reported in the 1970 census were adjusted for appreciation and inflation, so that values utilized in this study would be in 1975 dollars. The following indices additionally reflect regional differences in the cost of real estate:[51]

Indices of Real Estate Value

Location	1970	1975	Appreciation & Inflation Factor
Atlanta	127.5	181.0	1.42
Minneapolis	127.9	179.0	1.40
Seattle	126.3	174.9	1.38
U. S.	128.5	178.2	1.39

3.4 Cost Analysis of Three Airports

Utilizing data from Atlanta, Minneapolis, and Seattle, tables and graphs on the next few pages display population trends and other key characteristics. Discernible trends are particularly important, as conclusions established at this micro level will serve as the basis for generalizations needed to achieve a macro perspective at the national level.

Tables will be explained and discussed individually in sequence, as follows:

Table 3-2 – Distribution of housing units and population by L_{dn} noise level. With the exception of the L_{dn} 70 to 75 band for Atlanta, there is a clear trend of rapidly decreasing population and housing units as the noise level increases. This exception for Atlanta is the only such occurrence observed among the 23 airports.

Housing units and population for noise levels of 80 dB or more constitute only approximately 5 percent of the total subjected to significant aircraft noise $L_{dn} \geq 65$ dB. This means that a relatively small percentage of the population is subject to the highest noise levels.

Tables 3-3 and 3-4 – Aggregate noise insulation/relocation costs. These combine data previously presented in Section 3.3 (insulation and relocation costs for individual units) with housing and population data from Table 3-2. The result is a concise summary of aggregate costs for noise insulation or relocation under several possible noise policy goals.

Tables 3-5 and 3-6 – Comparison of selected data. These constitute the beginning of a transition to a model which reflects the national airport noise situation. Areas surrounding airports cannot be viewed in isolation. As a system, air transportation operates on a basis extending far beyond the jurisdictions within which its basic components (airports) are located. With this in mind, Tables 3-5 and 3-6 compare certain key characteristics for entire metropolitan areas with comparable characteristics for areas affected by airport noise. This reveals that areas subjected to airport noise, when compared to the overall metropolitan areas in which they are located, exhibit the following differences:

$L_{dn} \geq 85$: lower median value
lower gross rent
higher percent renter occupied

$L_{dn} \geq 75$: slightly lower median value
higher percent renter occupied

$L_{dn} \geq 65$: higher median value

Figures 3-1 and 3-2 – Median value and gross rent of property affected by airport noise versus SMSA median value and gross rent. (1) Except for median housing value in Seattle's $L_{dn} \geq 85$ noise zone, there is a distinguishable trend of decreasing median gross rent and median value in areas above L_{dn} 80 dB. (2) Up to L_{dn} 75 dB, median gross rent and median value are either increasing or are at least close to SMSA value and gross rent, indicating that airport proximity may be more of a value determinant than noise levels experienced in those areas.

Table 3-2

Distribution of Housing Units and Population by Day-Night Average Noise Level (L_{dn})

		L_{dn} Band, dB				
		65-70	70-75	75-80	80-85	≥ 85
Housing Units	Atlanta	6,387	10,230	3,157	2,786	698
	Minneapolis	13,216	10,649	2,706	0	0
	Seattle	24,238	8,887	2,070	882	70
	Average of 3 Cities	14,614	9,922	2,644	1,223	256
Population	Atlanta	20,343	40,398	19,526	11,048	1,847
	Minneapolis	42,741	31,937	8,014	0	0
	Seattle	57,261	30,744	6,439	2,740	185
	Average of 3 Cities	40,115	34,360	11,326	4,596	677

Table 3-3

Aggregate Noise Insulation Costs Under Various Assumptions of Airport Noise Policy Goals

	L_{dn}, dB			
	70	75	80	85
Atlanta	$153.49	$60.58	$19.68	$2.94
Minneapolis	$ 73.58	$10.96	0	0
Seattle	$ 76.16	$19.13	$ 4.17	$0.37
Average of 3 Cities	$100.35	$39.79	$ 7.80	$1.03
	Total cost to insulate affected housing units (those above desired level). (Millions of dollars)			

Note: Average of 3 cities is not simple arithmetic average.
Different indices used, as defined in Section 3.3.

Table 3-4

Aggregate Relocation Costs Under Various Assumptions of Airport Noise Policy Goals

	L_{dn}, dB			
	70	75	80	85
Atlanta	$399.25	$127.38	$61.54	$11.74
Minneapolis	$412.63	$ 73.82	0	0
Seattle	$308.86	$ 70.15	$21.87	$ 2.00
Average of 3 Cities	$373.19	$ 93.55	$27.42	$ 4.54
	Total cost to relocate (including purchase of land) affected persons from housing units above desired level (millions of dollars).			

Table 3-5

Selected Data for Households Subject to Airport Noise

	L_{dn}, dB	Median Value, Owner Occupied	Median Monthly Gross Rent	% Units Owner Occupied	% Units Renter Occupied	Average Household Size
Atlanta	≥ 85	$13,750	$ 96	31	69	2.65
	≥ 75	$14,500	$100	42	58	4.88
	≥ 65	$18,335	$110	58	42	4.01
Minneapolis	≥ 85	0	0	0	0	0
	≥ 75	$16,500	$140	66	34	2.96
	≥ 65	$16,950	$150	73	27	3.11
Seattle	≥ 85	$23,200	$100	53	47	2.64
	≥ 75	$19,000	$123	72	28	3.10
	≥ 65	$20,000	$ 98	51	49	2.69
Average of 3 Cities	≥ 85	$14,500	$ 96	33	67	2.64
	≥ 75	$18,500	$116	54	46	4.03
	≥ 65	$20,500	$116	60	40	3.18

Table 3-6

Selected Data for Households in U.S. and Overall Metropolitan Areas

	Atlanta**	Minneapolis**	Seattle**	U.S.	All SMSAs
Median Value, Owner Occupied*	$20,000	$21,600	$21,600	$17,100	$19,000
Median Monthly Gross Rent*	$117	$132	$129	$108	$115
Percent Units Owner Occupied	57	65	65	63	59
Median Household Size of Owner Occupied Units	3.2	3.5	3.0	3.0	3.1
Percent Units Renter Occupied	43	35	35	37	41
Median Household Size of Renter Occupied Units	2.4	2.0	1.9	2.3	2.2
Population	429,369	557,147	473,222	203,211,926	139,418,811
Housing Units	153,195	200,712	189,731	68,679,030	46,295,423
Median Household Size	2.8	3.0	2.6	2.7	2.7

* Adjuted for appreciation and inflation.

**Based on SMSA data for given area (Atlanta, Minneapolis-St. Paul, Seattle-Tacoma).

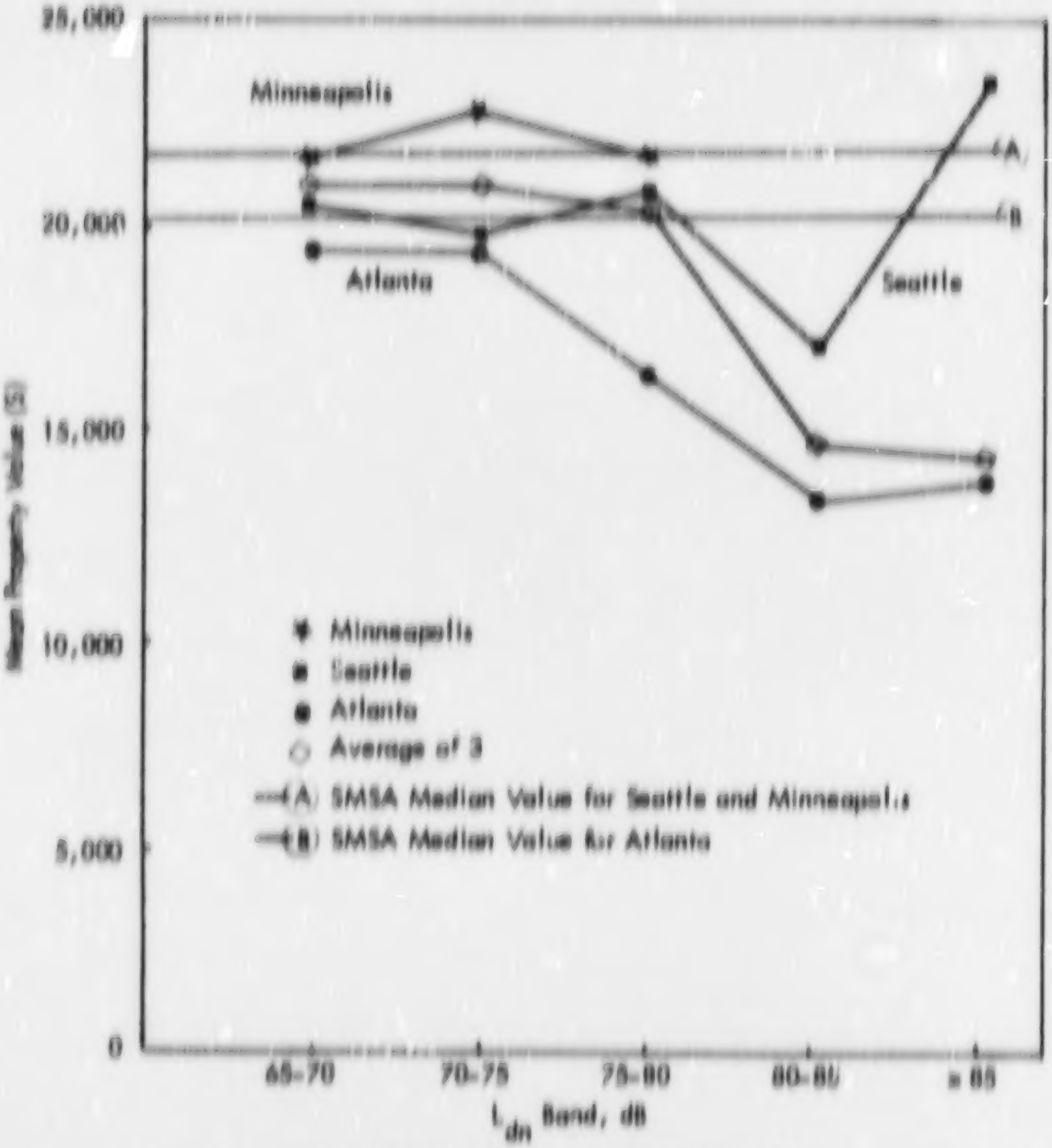

Figure 3-1. Median Value of Property Affected by Airport Noise Versus SMSA Median Value.

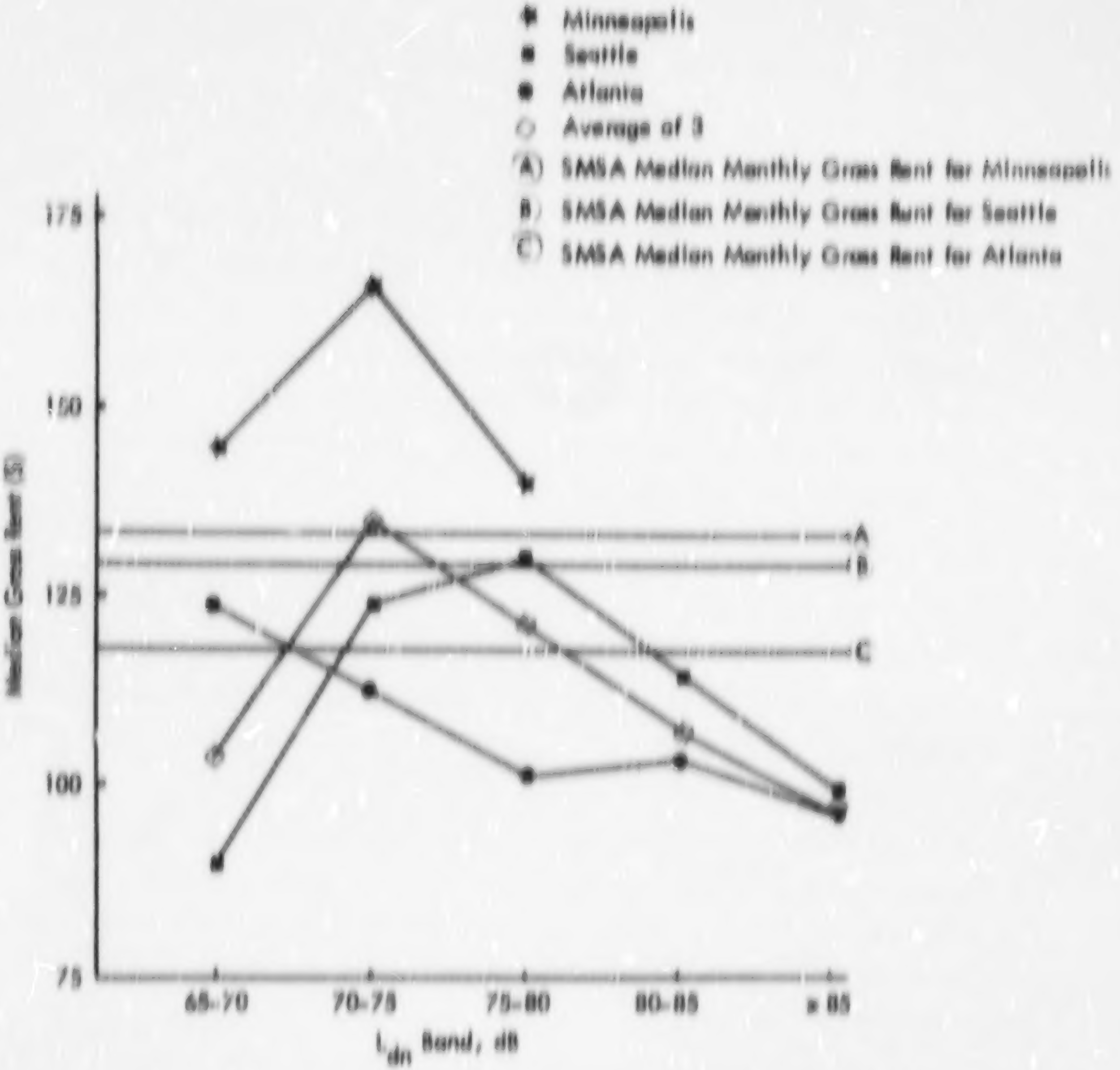

Figure 3-2. Median Gross Rent of Property Affected by Airport Noise Versus SMSA Median Monthly Gross Rent

3.5 Cost Analysis of Abatement Measures for Air Carrier Operations

The three aircraft abatement measures costed in this study are first, noise reduction treatment of JT3D/8D nacelles by sound-absorbent materials (SAM), second, a replacement of the JT8D engines currently in use (REFAN), and third, procedural changes in flight approach operations through the adoption of dual glide slope patterns (6°/3°). With the exception of applying SAM and REFAN to the same engine, these measures are not mutually exclusive; combination of two or three of these options have been examined.

3.5.1 Retrofit Alternatives

Costs of retrofitting engines of the existing fleet of aircraft are based on costs developed for the Wyle/DOT 23 airport study[1] and updated to reflect the revised fleet forecast for 1981 and the change in price levels between 1974 and September 1975. (The wholesale Price Index for transportation equipment rose by 12 percent during this period.)

The input data for the development of the original costs included initial investment costs as well as increased operating costs in terms of maintenance, insurance, and crew costs. These costs were discounted at a 10 percent rate to the present (1975) to arrive at the present value of outlays, customarily used in cost-benefit analyses.

Based on these assumptions, the following retrofit cost estimates were developed:

SAM 8D engines:	$283.4 million
SAM 3D engines:	$458.4 million

SAM 8D and 3D engines:	$741.8 million
REFAN 8D engines:	$2,593.2 million
REFAN 8D, SAM 3D engines:	$3,051.6 million

As stated, the present value formulation of costs is desirable for the conduct of cost-benefit analyses. For budgetary allocations, however, a formulation in terms of initial investment and annual operating costs is required.

The development of these costs requires assumption regarding the retirement dates of aircraft, by type, in the fleet. For the purpose of this analysis, the following retirement dates, based on data developed for the 23 airport study, are assumed:

B-737	1988	(8D)
DC-9	1988	(8D)
B-727	1988	(8D)
B-707	1986	(3D)
DC-8	1986	(3D)

Thus, the life expectancy of the 8D engines is assumed to be 13 years, while the life expectancy of the 3D engines is assumed to be 11 years.

These considerations are reflected in the following summary data of initial investment and annual operating costs for the SAM and REFAN programs under consideration.

	Retrofit Costs	
	Initial Investment $Million	Annual Operating $Million
SAM 8D Engines:	256.7	3.8
SAM 3D Engines:	322.3	21.0
SAM 8D and 3D Engines:	579.0	24.8
REFAN 8D Engines:	1711.0	125.8
REFAN 8D, SAM 3D Engines:	2033.3	146.8

3.5.2 Two-Segment Approach Alternative

A total of 2087 aircraft are forecasted to require on-board electronic equipment if the 6°/3° glide slope option is adopted by 1975. At an estimated cost of $35,000 each, the initial investment in this equipment is estimated to be $73 million.

In addition, 100 existing runways will have to be equipped with ILS/DME equipment at an estimated cost of $50,000 per runway for a total of $5 million.[55] Thus, the total initial cost of implementing the 6°/3° glide slope is estimated at $78 million. Operating cost of the electronic equipment and the procedural modifications are difficult to identify and judged to be negligible in the context of magnitude and precision of the other estimates presented.

3.5.3 Fuel Cost Considerations

Since fuel costs command an increasing percentage of variable flight costs, it appeared desirable to examine the impact of abatement measures at the source on fuel consumption. Many of the interrelationships encountered are, however, extremely complex. Research of available publication as to the likely impact of abatement options on fuel consumption does not appear to yield information which will permit determination of the impact with an acceptable degree of confidence based on any anticipated changes in the economy. In lieu of this, a qualitative assessment reflecting consensus judgment is presented below.

An additionally complicating factor is the fact that test data on fuel consumption is normally obtained from new engines. The effect of engine aging on fuel consumption is not well researched and documented. Speculation as to the possible impact of modifications on fuel consumption must, therefore, be superimposed on the uncertainty associated with stipulated consumption estimates.

The nacelle soundproofing option (SAM) is expected to add to the empty weight of the aircraft without in any way increasing the efficiency of the engine. As a consequence, this abatement option can be expected to increase fuel consumption slightly and thereby also the variable flight cost of the aircraft.

The REFAN option is expected to have two contradictory effects as far as fuel consumption is concerned. First, the refanned engine is designed to be more efficient reducing fuel consumption from present designs. The second effect, however, is the extra weight added by the redesigned engines, resulting in higher thrust requirements for takeoff and thereby increased fuel consumption. On balance it is expected that total fuel consumption per flight will remain approximately at prevailing levels.

Superimposed on these modification options are operational and procedural changes in flight profiles which are under consideration. Prominent among these is the $6^\circ/3^\circ$ approach option. While experimental data are not readily available, it is alleged that this approach might potentially have a side benefit of reduced fuel consumption. Precise estimates are not readily available.

In summary, the subject of fuel economics of noise abatement options is a most complex issue lacking credible estimates. Furthermore, in view of the expected fuel price increases, it is not a trivial issue. However, in the absence of empirical data, a detailed forecast of likely outcomes must be considered beyond the scope of this study.

3.5.4 Cost Considerations of the Curfew Alternative

The effectiveness of the night curfew alternatives in terms of reduction in area/population impacted are self-evident in this study. Treating reduction in noise impact as a benefit, the benefits for curfew options are as great or greater than the benefits derived from the retrofit alternatives. The disbenefits of enforcing night curfews are, [illegible]ver, less clear. Cost considerations include the costs to the airlines, the airports, the passengers, and the other local, regional, or national economies.

Curfew analyses in the past have dealt with the impact of such restrictions on the operations of a single airport. This is quite different from the assumptions applied in this study which demonstrated the effect on a total national scale. A city/airport, for example, competing for the business or travel dollar with another city may consider itself less competitive when it has a curfew and when its competition does not.

The question of curfew has been a much debated issue which rests on diverse points of view depending on the particular vested interest. The concerns expressed fall into four general categories. These categories are:

- "Quiet"
- Safety
- Preference
- Revenue Loss

The aspects of "quiet" are obvious. The increased need for quiet during nighttime hours and the increased sensitivity of people to noise intrusion during this period has been well documented.[34] Safety, on the other hand, is a major concern of aviation authorities. Reasonably, aircraft which are unavoidably delayed in flight and/or are involved in potential or real emergency situations cannot be expected to stay in the air waiting for the curfew to lift. This obviously necessitates some minimum continuous 24-hour capability at each airport.

Preference refers to the way things are commonly done or accepted as standard practice with a good measure of assumed convenience. Night curfews present scheduling problems to airlines. Scheduling in this instance refers to passenger convenience and/or cargo deliveries in a competitive market. End-of-day pickup and next-morning delivery is a competitive edge. Off-peak hour or nighttime operations of air cargo is an accepted activity the world around. Passenger schedules are developed in conjunction with the work, leisure and diurnal cycles of people, particularly on long haul multistop flights which cover several time zones. Charter operations also fall into this category. Some airlines offer discount rates for the "midnight specials" which are a competitive convenience for the economy-minded passenger.

The category of "revenue loss" associated with night curfew may have far more complex implications. Operating costs to the airlines may result from a requirement to increase fleet and crew size due to the under-utilization of aircraft which will also increase the annual depreciation rate.

Immobile aircraft do not make money. Loss of a route, additional costs of unscheduled stopovers, technical and traffic handling fees, passenger and crew accommodations and general passenger inconvenience which may lead to some loss in passenger demand are all considerations in curfews especially for long haul operations. The major cost items, however, will be in the areas of delays and congestion. These costs have been addressed in a previous EPA report.[3] Table 3-7 provides a summary of the curfew costs presented in the referenced report. The report also concludes that air cargo, air mail, maintenance and repair, and international operations will have a minimum cost impact, if any, and that some of the operating costs would most likely be offset by the increase in noncurfew hour load factors and the overall cost benefits associated with the decrease in noise-impacted land areas.

Table 3-7

Summary of Curfew Costs[3]*
(Millions of 1973 Dollars)

YEAR	DELAY TIMES (000 MINUTES)	AIRLINE OPS COST INCREASE (1)	AIRLINE LOST CARGO REVS. (2)	AIRLINE DELAY COSTS (3)	USER DELAY COSTS (4)	TOTAL (5)
1974	5139.8	7.30	3.77	39.06	36.06	86.19
1975	5353.4	7.83	4.13	40.68	37.56	90.20
1976	5567.4	8.40	4.51	42.31	39.06	94.28
1977	5761.2	9.06	4.92	43.93	40.56	98.47
1978	5956.1	9.75	5.31	45.56	42.06	102.68
1979	6208.9	10.54	5.87	47.18	43.56	107.15
1980	6433.7	11.37	6.22	48.81	45.06	111.46
	TOTALS	64.25	34.73	307.53	283.92	690.43

---

*The assumptions applied in the construction of this table are as follows:

- On a national level, night flights represent approximately 15 percent of the total daily activity.
- With a night curfew, one-third of the night flights are rescheduled to daytime, resulting in a 10 percent overall decrease in flight activity.
- Half of this activity will not be replaced, and passengers will travel on noncurfew flights which will increase the noncurfew flight load factors.
- The remaining 5 percent affected aircraft movements may require airlines to purchase new equipment to compensate for decreased aircraft activity.

These assumptions are different from the curfew conditions demonstrated in the present study which either assume a rescheduling of all nighttime flights to daytime (Curfew "A") or the total elimination of night activity (Curfew "B").

Operations and revenue loss by airports could include lower revenue from landing fees, gasoline sales profits, handling fees, concession operations, parking and other services. Other disbenefits accrue to the local economy as a whole and are expressed in both near and long term economic vitality. Reduction in visitor expenditures and service requirements affect jobs and local businesses and could ultimately reduce the general competitive strength of the demand for local goods and services and loss in the local gross product.

The disbenefits which have been briefly discussed here relate primarily to curfews as may be enforced on an airport by airport basis. As was pointed out earlier, this study assumed a national curfew enforced equally at all airports. Many of the disbenefits may therefore be resolved when everyone is wearing the same "shoe." Thus, a realistic evaluation of revenue loss (or gain) as a result of any given national curfew policy would involve an operations analysis of the total national and international air carrier system – an analysis well beyond the scope of this study.

3.6 Cost Analysis of Nationwide Abatement Measures

The national population data for noise contour levels of L_{dn} 65 dB or more follows the general trend previously indicated in the three-airport analysis, i.e., progressively fewer persons as the noise contour level increases.

Potential costs for noise insulation and relocation depend upon the number of housing units rather than the overall population affected. It is therefore vital to develop a logical means of transforming the national population data into firm estimates of housing units.

Under an initial hypothesis that household size might depend primarily on population density, Figure 3-3 was developed. It is evident that a significant trend does not emerge from these data which would justify varying household size with density. As an alternate approach, household size for the three airports was plotted against the noise contour level. This procedure, as illustrated in Figure 3-4, revealed the following trends in household sizes versus L_{dn} bands for the 1972 baseline contours.

L_{dn} Band, dB	Household Size (Persons/Household)
65-69	2.7
70-74	3.0
75-79	3.0
80-84	3.3
≥ 85	2.7

These results, when veiwed in terms of median property values for the various noise contour levels, conform to the previously-discussed finding that elasticity of demand for residential quiet is approximately two. As median value of housing decreases, the housing stock becomes increasingly attractive for households of a lower-income level. Historically, lower income groups have exhibited larger household sizes than income groups above them. Hence, one would expect household size to increase above an L_{dn} of 70 dB, since this is the approximate point at which median values began to decrease in the three-airport analysis. However, an L_{dn} of 85 dB is apparently viewed as a critical point by the market

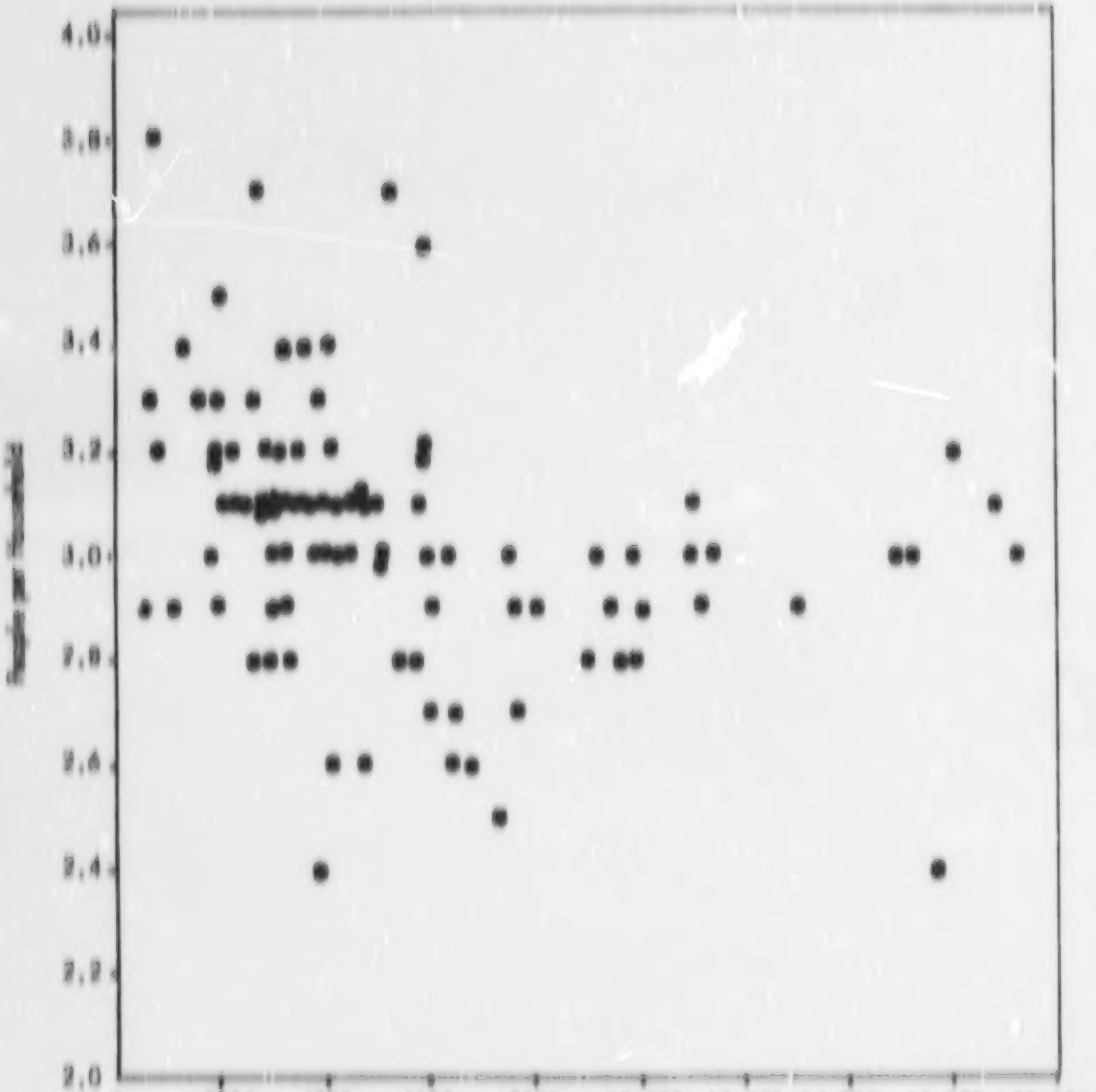

Figure 3-3. Household Size of 100 Largest U.S. Cities Versus Population Density of Incorporated City (from 1970 Census)[52]

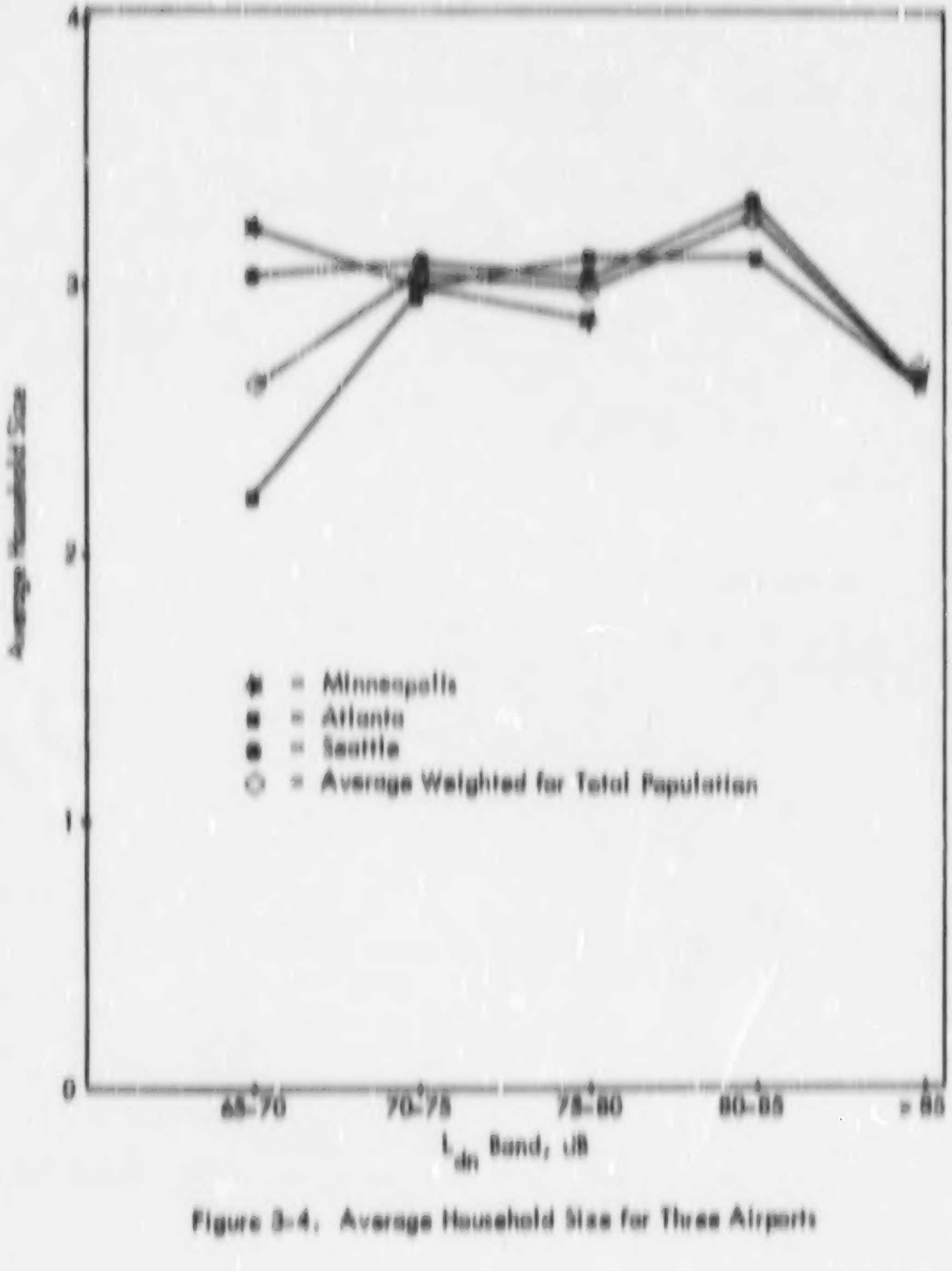

Figure 3-4. Average Household Size for Three Airports

and is sufficiently extreme to reduce its attractiveness to larger families above that point. Therefore, a reduction in household size is witnessed at this noise level.

Since this trend is consistent with available empirical data, this relationship between household size and L_{dn} bands was then utilized to transform national population data to housing units. Table 3-8 provides the national population for each L_{dn} band with the number of housing units listed below. (Housing units were derived by dividing population by household sizes discussed above.) In all cases, the baseline population distribution versus L_{dn} band for each year was used to establish the number of households by L_{dn} band. This approach to the determination of the number of households impacted by airport noise for the nation is, admittedly, empirical but offers a rational basis for utilizing the ± 10 percent variation in household size observed in the detailed census data for the three sample airports.

It is important to recognize that due to this variation in household size with L_{dn}, the number of households could only be established for the baseline cases for each year. Any reduction in L_{dn} due to a noise reduction alternative changes the number of people impacted within each L_{dn} band but the population is still in the same location so that an estimate of the number of households impacted with the reduced L_{dn} levels is not possible. If necessary, however, one could make a rough estimate of the number of households impacted for any alternative by dividing the population impacted by three, an average household size.

Tables 3-9 and 3-10 summarize composite noise insulation and relocation costs for a national program. Noise insulation costs were computed by applying

Table 3-8

National Population and Housing Units, As Distributed in Noise Contour Levels

Criteria Base Years & Abatement Alternatives	Total Population (P) / Total Housing Units (H)	Household Size (Number of Persons)*				
		2.7	3.0	3.0	3.3	2.7
		L_{dn} Band, dB				
		65-70	70-75	75-80	80-85	≥85
1972 Base	P	5,019,300	1,453,900	477,100	124,200	15,000
	H	1,859,000	484,633	159,033	37,636	5,556
1981 Base	P	3,181,000	1,100,800	314,700	54,900	3,000
	H	1,178,148	366,933	104,900	16,636	1,111
1981 SAM 8D/3D	P	2,303,020	886,700	238,600	37,300	1,500
1981 6°/3°	P	2,870,300	764,900	283,800	55,600	3,000
1987 Base	P	3,482,500	1,208,600	348,400	61,900	3,500
	H	1,289,815	402,867	116,133	18,756	1,296
1987 SAM 8D/3D	P	2,763,900	983,200	266,700	43,000	1,900
1987 6°/3°	P	3,140,500	1,062,600	313,400	61,900	3,500

*Applicable for baseline case only

Note: Assume housing units versus L_{dn} only applies to base conditions – the change in L_{dn} due to any alternative does not change number of people/housing units.

Table 3-9

Noise Insulation Costs (Millions of Dollars)

Alternative (Total Units)	Reduction		
	5 dB	10 dB	15 dB
1972 Base (2,545,797)	$10,158	$15,268	$17,161
1981 Base (1,667,729)	$ 6,654	$10,297	$11,443
1987 Base (1,828,778)	$ 7,297	$11,308	$12,582

Note:

(See text for basis of calculation at each level of noise reduction treatment)

Table 3-10

Land Acquisition and Relocation Costs - For Each Individual Band
(Costs in Millions of Dollars)

Criteria Base Years	L_{dn} Levels					
	65-70	70-75	75-80	80-85	≥ 85	Total
1972 Base	$36,343	$9,475	$3,109	$735	$109.0	$49,771.0
1981 Base	$23,033	$7,174	$2,051	$325	$ 21.7	$32,605.0
1987 Base	$25,216	$7,876	$2,270	$367	$ 25.3	$35,754.0

Note:

Calculations based on:

- urban median value = $19,000
- moving cost = $550
- $19,550 × number of housing units

U.S. average costs from Table 3-1 to the given number of housing units. Column headings list reductions which were applied to all housing units (≥L_{dn} 65 dB) with the proviso that L_{dn} 60 dB is the lower limit to which reductions will be made. Therefore, under 10 dB and 15 dB noise reduction treatment, housing units in the L_{dn} 65-70 dB bands are only reduced by 5 dB, while under a 15 dB noise reduction treatment, units in the L_{dn} 70-75 dB band are only reduced by 10 dB. Relocation costs were computed by applying a cost of $19,550 to each housing unit. ($550 = moving costs per housing unit, as developed previously; $19,000 = median value for urban housing in the U.S., as reported in Table 3-6.) As is evident from Figure 3-2, at least 85 percent of the baseline units in the three-airport analysis exhibit median values which are nearly equivalent to the median values for their respective SMSAs. At higher noise levels, the trend is inconsistent.

Costs for source abatement measures were developed in section 3.5. Briefly, the SAM 8D/3D program would cost $741.8 million; the 6°/3° glide slope pattern program would cost $78 million. Relocation, noise insulation, and adoption of the 6°/3° glide slope pattern are assumed to involve initial investment costs only. (Annual operating costs of 6°/3° procedures are considered negligible.) The SAM program involves both initial investment costs and annual operating costs as delineated in section 3.5. Possible annual energy savings for homes treated with noise insulation has also been neglected. For the higher levels of noise reduction, any such savings would tend to be counterbalanced by added annual costs of operating an air supply system required for such noise insulation treatment.

3.7 Minimum Cost Solutions

As can be seen, no attempt has been made in this study to present and evaluate the array of minimum cost solution sets possible. This was beyond the scope of the present effort. The foundations, however, are provided from which such an analysis can be derived and which should subsequently be pursued.

There are many potential combinations of source, operational and receiver noise abatement alternatives which should be examined for their cost-effectiveness and socioeconomic interrelationships.

When technically feasible, abatement options can be combined to minimize overall costs for each of several threshold levels indicated. For example, if an L_{dn} of 70 dB is specified, the goal might be met through operational modifications requiring installation of 6°/3° approach equipment in the fleet plus soundproofing homes located in the 70 to 80 dB band and moving all residents located in bands above 80 dB. Other combinations such as SAM treatment of the fleet in addition to or in lieu of other options can be attempted until only very limited improvements are observable.

3.8 Cost Considerations for Noise Reduction of the General Aviation Fleet

Cost factors involved in reducing noise of the general aviation fleet have been considered in recent EPA project reports on a noise certification rule for propeller aircraft,[53] (1) and (2) noise standards for civil subsonic turbojet and turbofan aircraft.[32] Relevant information from these studies is utilized here as a basis for considering the cost of general aviation noise reduction.

3.8.1 Propeller Aircraft

Although the estimated noise impact around the nation's general aviation airports shows essentially no people inside the L_{dn} 65 at airports without any business jets (see Section 4.3), the cost of reducing propeller aircraft noise deserves consideration due to the overwhelming preponderance of propeller aircraft in the general aviation fleet.

As a result of studies stimulated by the Airport and Airways Development and Revenue Act of 1970 (Public Law 91-258), the economics of the general aviation fleet has been studied extensively in the General Aviation Cost Impact Study.[54]

One of the most important results of this study is that in order to properly assess the economic impact on this industry of any aeronautical noise reduction alternatives involving retrofit or purchase of new equipment, the general aviation class must be segmented, not only by the different types of aircraft, but also by the different aircraft user categories. This is demonstrated more clearly by examining the variation in cost elasticity for various user categories in the general aviation fleet. Table 3-11 shows this data from Reference 53. The number of aircraft and total hours usage by aircraft type, and type of usage, as of 1971, are shown in Table 3-12.

Table 3-11

Elasticity of Costs for the General Aviation Fleet(1)
(Reference 53)

User Category	Fixed Cost Elasticity	Operating Cost Elasticity
Business and Executive	1,203	0,699
Personal	3,578	1,350
Air Taxi	4,516	0,304
Instructional	0,478	2,237(2)
Aerial Application	2,777	1,695
Industrial/Special	0,852	0,772

(1) $\text{Elasticity} = \frac{\text{Percent Change in Activity}}{\text{Percent Change in Cost}}$

(2) Elasticity with respect to hourly cost; including an allowance to cover annual fixed costs based on annual utilization.

Table 3-12

Number of Aircraft and Hours of Usage (in thousands) for General Aviation Fleet as of 1971

(Reference 54)

Aircraft Type		Factor	Usage					
			Business and Exec.	Personal	Instructional ②	Commercial ③	Other	Total
Piston	1 Engine	No. Hrs.[1]	32,633 3812.3	65,847 7472.7	16,803 6827.2	9045 2542.6	1687 279.4	119,064 20,934.4
	Multi-Engine	No. Hrs.	10,701 3026.3	2421 356.3	821 238.0	2548 1137.2	594 83.5	17,085 4841.6
Turbo-prop	< 12,500 lb.	No. Hrs.	772 404.8	16 4.0	3 2.4	229 352.6	47 12.5	1067 776.3
	> 12,500 lb.	No. Hrs.	223 166.7	1 0.5	1 0.2	7 8.3	4 0.4	236 176.0
Jet	< 20,000 lb.	No. Hrs.	418 237.0	9 3.0	1 0.3	48 26.8	28 10.9	504 278.0
	≥ 20,000 lb.	No. Hrs.	299 287.1	9 6.7	0	3 0.7	26 29.5	337 324.2
Rotary Wing	Piston	No. Hrs.	283 74.4	108 8.6	106 23.4	1360 460.3	68 16.6	1925 583.3
	Turbine	No. Hrs.	204 73.4	92 6.8	7 2.5	343 170.5	43 23.6	689 276.8
Other		No. Hrs.	308 17.0	4471 174.0	584 72.3	256 111.0	613 37.0	6232 413.3
Total		No. Hrs.	38,951 8101.1	76,104 8044.5	18,380 7168.4	13,844 4819.2	3322 493.5	147,021 28,606.1

[1] Hours in Thousands

② Includes training and rental.

③ Includes air taxi, aerial applications and industrial/special.

Noise reduction technology for general aviation propeller aircraft will primarily involve use of quieter propellers and/or improved exhaust mufflers. Typical noise reductions and cost impact associated with changing from a two-blade to a three-blade (quieter) propeller are listed below.

Aircraft	Base Price (1)	Percent Price Change (2)	Relative Noise Level (2)
Single Engine (285 hp)	$46,000	+1.05	-8.3 dB
Twin Engine (570 hp)	$92,600 to $108,850	+1.3 to 1.5	-3.0 dB

(1) For two-bladed propeller

(2) For three-bladed propeller relative to two-bladed propeller

The cost impact to a new aircraft for a quieter three-bladed propeller is obviously small. Any propeller retrofit program, however, could be very costly. Assuming an average cost of $1000 per aircraft to retrofit propellers and assuming, say, 50 percent of the propeller aircraft fleet required such a retrofit, the one-time investment cost for the fleet in, say, 1981, with about 190,000 propeller aircraft, would be $95 million.

Cost data for improved mufflers for piston and turboprop engines were not available. Estimates, however, suggest that muffler retrofit costs would be substantially less than the preceding estimate for propellers and noise reduction of about 6 dB could be expected.[53]

3.8.2 Business/Executive Jet Aircraft

According to an analysis of the business jet fleet conducted by EPA in support of proposed noise standards for jet aircraft, approximately 80 percent are powered by straight turbojet or low bypass ratio turbofan engines.[32] Noise levels for these aircraft range from just meeting FAR 36 to substantially exceeding FAR 36. The remaining 20 percent of the business jet fleet are powered by more recent technology higher bypass ratio turbofan engines which are much quieter than FAR 36 requirements.

Estimated costs of modifying the United States business jet fleet to comply with FAR 36 levels are given in Table 3-13.

Table 3-13

Costs of Reengine or Suppressor Retrofit for Business Jets (Adopted from Reference 32)[a]

AIRPLANE			Cost in Millions of 1975 Dollars			
TYPE & MANUFACTURER	ENGINE (EXISTING) & MANUFACTURER	QUANTITY (US ONLY)	UNIT COST (INSTALLED WITH SPARES)		INVESTMENT COST (UNIT COST x QUANTITY)	
			REENGINE	SUPPRESSION	REENGINE	SUPPRESSION
LEARJET GATES LEARJET	2 CJ610-6 GENERAL ELECTRIC	81	.441	-	35.7	-
WESTWIND 1121/23 ISRAEL A/C IND.	2 CJ610-9 GENERAL ELECTRIC	134	.44	-	59.1	-
SABRE ROCKWELL INT.	2 JT12A-8 PRATT & WHITNEY	63	.601	-	37.8	-
HS-125 HAWKER SIDDELEY	2 VIPER 601 ROLLS ROYCE	142	-	.123	-	17.4
JETSTAR LOCKHEED	4 JT12A-8 PRATT & WHITNEY	124	1.655	-	205.3	-
GULFSTREAM 2 GRUMMAN	2 SPEY MK 511-8 ROLLS ROYCE	113	-	.184	-	20.8
		657		Subtotal	337.8	38.2
				Total	376.0	

[a] 1973 cost figures increased by 22.6 percent for inflation.

The seven airplanes listed are those exceeding the FAR 36 criteria as of December 1974. Two of the airplanes (HS-125 and Gulfstream 2) can be made to comply by modifying the exhaust nozzles to include noise suppression devices. The other airplanes can comply only by replacing the existing straight turbojet or low bypass ratio turbofan engines with high bypass ratio turbofan engines which are substantially quieter.[32]

It is estimated that the noise level reductions available from the business jet retrofit options would be somewhere within the design goal range. This would mean a noise reduction at the FAR 36 measuring points of as much as 5 to 10 EPNdB for some airplanes (e.g., Westwind and Gulfstream 2). The estimated maximum investment cost for FAR 36 compliance for the 657 airplanes listed in Table 3-13 is about $376 million in 1975 dollars. This has been adjusted from the 1973 cost figures in Reference 32 to reflect the inflation in the transportation price index of 22.6 percent from 1973 to 1975. Data on potential increased operating costs for these reengine or retrofit options for the noisier portion of the business jet fleet were not available. However, since the greatest portion of the total initial investment would be for new, probably more efficient, turbofan engines, any changes in annual operating costs are not likely to be a major factor in the economics of retrofitting the business jet fleet. Financing of the initial investment required, however, may be a major hurdle with fewer viable options than are available for financing any retrofit programs for the air carrier fleet. More detailed data on potential cost implications of modifying the general aviation fleet can be found in Reference 54.

As discussed at the end of Section 4 (pp 4-17), the relatively small noise impact of flight operations at general aviation airports (relative to the noise impact from commercial air carrier aircraft) will tend to be dominated by noise from business jets. At air carrier airports, the proportion of business jet operations will undoubtedly increase in the future but this increase will come primarily from new business jet aircraft introduced into the fleet which will inherently be as quiet or quieter than the air carrier aircraft by virtue of FAR 36 requirements. Thus, the impact of business jet operations at air carrier airports is expected to remain relatively insignificant.

4.0 COST-EFFECTIVENESS OF SOLUTION SETS

4.1 Introduction

The preceding two chapters have shown the methods used to define effectiveness of noise reduction alternatives in terms of noise impacted population (Section 2), and costs in terms of present value (1975) dollars for those solutions for which costs could be assigned (Section 3). This section brings these two areas together to present final results by cost and/or effectiveness of all the noise reduction alternatives considered.

The "effectiveness" of any alternative is actually portrayed in several ways:

- The total area for the nation within noise level bands (e.g., area between the L_{dn} 65 and L_{dn} 70 contours). The L_{dn} bands evaluated are those between 65 to 70, 70 to 75, 75 to 80, 80 to 85, and greater than 85 dB. Strictly speaking, the L_{dn} bands extend from $\geq$ 65 to $<$ 70 dB, $\geq$ 70 to $<$ 75 dB, etc. The values indicated were computed from the cumulative noise impact data in Section 2.
- The total national population impacted within each such L_{dn} band.
- The number of housing units (for the base cases only) within each L_{dn} band.

- The Noise Units (NU) corresponding to this population computed as defined in Section 2.6.
- The change (Δ NU) in Noise Units relative to the corresponding baseline value for the same year and L_{dn} band.

The cost of each aeronautical alternative (except the FAR 36-10 dB alternative which was assumed to be obtained at no cost in the normal course of new aircraft development) is presented from the data in Section 3. Similarly, costs for the receiver alternatives were obtained from the methods and data presented in Section 3.

4.2 Cost-Effectiveness for Solution Sets Around Air Carrier Airports

4.2.1 Baseline and Power Cutback Alternatives

The final results for the nation's air carrier airports are presented in the following tables. Table 4-1 defines the noise impact parameters for the baseline conditions for 1972, 1981, and 1987, as well as the results for the power cutback alternative for the later two years. Note that the total contour area decreases from 1972 to 1981, but remains nearly the same from 1981 to 1987. However, due to the use of an assumed population growth of 10 percent for 1981 (relative to 1972) and 20 percent for 1987 (relative to 1972), the impacted population and corresponding noise units increase slightly from 1981 to 1987.

The power cutback alternative shows a net increase in impacted population and noise units for the nation when it is applied universally at all airports. This

Table 4-1

Summary Table of Results – Baseline and Power Cutback Cases

Year	Alternative	Factor	L_{dn} Band						
			65-70	70-75	75-80	80-85	≥ 85	Total	Units
1972	Base	Contour Area	1711.0	626.7	231.0	98.7	73.6	2741.0	Sq. Mi.
		Population	5019.3	1453.9	477.1	124.2	15.0	7089.5	x 1000
		Housing Units	1859.0	484.6	159.0	37.6	5.6	2545.8	x 1000
		Noise Units	2962.1	1279.5	549.9	175.0	24.9	4991.4	x 1000
1981	Base	Contour Area	1257.6	481.7	178.9	76.0	52.0	2046.2	Sq. Mi.
		Population	3181.0	1100.8	314.7	54.9	3.0	4654.4	x 1000
		Housing Units	1178.1	366.9	104.9	16.6	1.1	1667.6	x 1000
		Noise Units	1973.3	972.3	365.0	77.4	5.0	3393.0	x 1000
1987	Base	Contour Area	1248.5	482.5	177.8	73.8	52.2	2034.8	Sq. Mi.
		Population	3482.5	1208.6	348.4	61.9	3.5	5104.9	x 1000
		Housing Units	1289.8	402.9	116.1	18.8	1.3	1828.9	x 1000
		Noise Units	2090.8	1403.9	404.2	87.2	5.8	3631.9	x 1000
1981	PCB	Contour Area	1422.4	410.0	158.3	73.5	52.0	2116.2	Sq. Mi.
		Population	3799.5	873.2	252.9	50.8	3.0	4979.4	x 1000
		Noise Units	2314.6	784.4	293.3	71.6	5.0	3468.9	x 1000
		Δ NU						(75.9)*	x 1000
		Cost						0	$M
1987	PCB	Contour Area	1571.9	401.5	154.5	70.8	52.2	2250.9	Sq. Mi.
		Population	4202.1	939.6	276.4	56.7	3.5	5478.3	x 1000
		Noise Units	2559.2	825.2	320.6	79.9	5.8	3790.7	x 1000
		Δ NU						(158.8)*	x 1000
		Cost						0	$M

*( ) Signifies increase in NU.

is the expected result on the basis of the AVport analyses carried out in Section 2. It is due to the fact that the net reduction in noise impacted area corresponding to the lower noise generated by power cutback is cancelled out by the higher noise levels on the ground as a result of a lower climb profile (See Figure 4-1). This anomalous behavior is most apparent in the 65 to 70 L_{dn} band for the larger airports as indicated in Table 4-2. This shows the change in number of people impacted for power cutback cases (relative to the 1987 base) for each L_{dn} band and AVport category for the year 1987.

The table shows that PCB does, in fact, provide a substantial decrease in the number of people impacted at L_{dn} levels of 70 and above for the large airports, but provides very little benefit for the smallest category of airport. The data also suggest that a more effective uniform PCB procedure might have been obtained by delaying initiation of power cutback until the aircraft reach a higher altitude. This point deserves further optimization.

It is also important to recognize that use of PCB at those airports where the takeoff tracks lie over unpopulated areas in the 65 to 70 L_{dn} band will still show a net benefit with the use of PCB.

4.2.2 Modified Approach Glide Slope Alternative

The costs and benefits predicted with the use of an increased glide slope (4°) or two-segment (6°/3°) approach are shown in Table 4-3. Although the total decrease in noise units on impacted population, across the nation, is small for these low cost alternatives, they should provide substantial benefits at airports such as Los Angeles International Airport where noise impact is dominated by approach noise. It is also important to note that the 4° glide slope is not

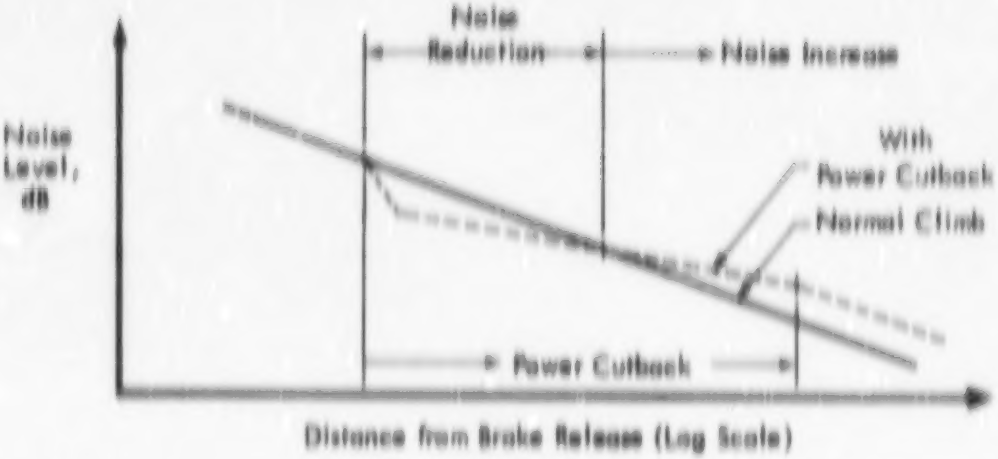

Figure 4-1. Illustration of Regions of Noise Reduction and Noise Increase for Power Cutback Takeoff Procedures

Table 4-2

Change in Number of People Impacted Due to Power Cutback Procedure for 1987

Airport	Δ Population/ Δ Percent	L_{dn} Band 65-70	70-75	75-80	80-85	≥ 85	Total
I (≥ 100 Operations Per Day)	Δ Population (000)[1]	+709.7	-256.8	-70.3	-5.2	0	+377.4
	Δ Percent[2]	+23.4	-23.8	-21.1	-8.5	0	+8.4
III (40-99 Operations Per Day)	Δ Population (000)	+20.6	-12.2	-1.2	0	0	+6.7
	Δ Percent	+8.2	-14.8	-11.9	0	0	+1.9
II (10-39 Operations Per Day)	Δ Population (000)	-10.7	0	0	0	0	-10.7
	Δ Percent	-5.4	0	0	0	0	-4.2

[1] Change in number of people (in 1000's) relative to 1987 base due to power cutback.

[2] Change in number of people (in percent) relative to 1987 base due to power cutback.

Table 4-3

Summary Table of Results - 4° and 6°/3° Approach Cases

Year	Alternative	Factor	L_{dn} Band						
			65-70	70-75	75-80	80-85	≥85	Total	Units
1981	4° Approach	Contour Area	1253.9	426.2	161.2	72.9	49.7	1963.9	Sq. Mi.
		Population	3198.6	955.2	269.8	47.5	2.4	4473.5	x 1000
		Noise Units	1978.7	847.7	312.9	66.9	4.0	3210.2	x 1000
		Δ NU						182.8	x 1000
		Cost						0	$M
1987	4° Approach	Contour Area	1242.1	432.1	161.6	69.2	50.4	1955.4	Sq. Mi.
		Population	3490.0	1068.5	298.4	54.2	2.9	4914.0	x 1000
		Noise Units	2090.1	925.8	346.1	76.4	4.8	3443.3	x 1000
		Δ NU						188.6	x 1000
		Cost						0	$M
1981	6°/3° Approach	Contour Area	1172.2	438.2	167.2	76.4	52.0	1906.0	Sq. Mi.
		Population	2870.3	964.9	283.8	55.6	3.0	4177.6	x 1000
		Noise Units	1799.6	859.9	329.2	78.3	5.0	3072.1	x 1000
		Δ NU						320.9	x 1000
		Cost						78.0	$M
1987	6°/3° Approach	Contour Area	1159.3	439.5	166.6	73.8	52.2	1891.4	Sq. Mi.
		Population	3140.5	1062.6	313.4	61.9	3.5	4581.9	x 1000
		Noise Units	1904.5	925.8	363.5	87.2	5.8	3286.9	x 1000
		Δ NU						345.0	x 1000
		Cost						78.0	$M

significantly beneficial outside the L_{dn} 70 contour (for the national model), but the 6°/3° glide slope alternative is more beneficial at the lower L_{dn} values – (i.e., at farthest distances from the airport). For both of these alternatives, the predicted effectiveness is obviously sensitive to the assumption made about the relative mix of landing and takeoff traffic for each of the AVport flight tracks; however, the relative reduction in impacted people, or in noise units for the 6°/3° alternative (of the order of 8 to 10 percent for the nation), is comparable to a similar estimate made in a previous study of national noise impact.[2]

4.2.3 Curfew Alternatives

The expected very large reduction in noise impact obtained by curfew options is indicated by the data in Table 4-4. Note that the effectiveness obtained in rescheduling all night flights (10 PM to 7 AM) to daytime hours is nearly as great as that obtained by simply eliminating the night flights. Thus, the added noise impact of more daytime flights is more than offset by the elimination of the night flights due to the weighting factor of 10 used in the L_{dn} formula for nighttime flights.

As discussed in Section 3, no costs are attributed to these curfew options since they are assumed to be applied universally at all airports. An accurate cost analysis of this type of universal curfew would require a detailed analysis of the air carrier system in order to provide a valid measure of the tradeoff between cost savings resulting from fewer flights or operating hours as opposed to cost increases to handle greater traffic flow or potential revenue losses due to decreased passenger enplanements. For purposes of this report, therefore, it was necessary to assume a long-term assignment of zero cost to national curfew alternatives.

Table 4-4

Summary Table of Results - Curfew Cases

Year	Alternative	Factor	L_{dn} Band						
			65-70	70-75	75-80	80-85	≥ 85	Total	Units
1981	Curfew - Night Flights Rescheduled to Day	Contour Area	634,2	234,0	96,9	38,9	27,5	1031,5	Sq. Mi.
		Population	1560,4	493,7	110,8	9,8	0,2	2174,9	x 1000
		Noise Units	976,8	444,5	128,5	12,8	0,3	1563,9	x 1000
		Δ NU						1829,1	x 1000
		Cost						-	$M
1981	Curfew - Night Flights Eliminated	Contour Area	553,1	207,4	85,9	33,7	25,8	905,9	Sq. Mi.
		Population	1370,7	425,7	89,4	6,9	0,2	1892,9	x 1000
		Noise Units	856	385,8	103,7	9,7	0,3	1355,5	x 1000
		Δ NU						2037,5	x 1000
		Cost						-	$M
1987	Curfew - Night Flights Rescheduled to Day	Contour Area	651,5	241,5	99,0	39,4	29,4	1060,8	Sq. Mi.
		Population	1769,1	575,8	133,4	12,9	0,3	2491,5	x 1000
		Noise Units	1071,8	503,4	154,7	18,2	0,5	1748,6	x 1000
		Δ NU						1883,3	x 1000
		Cost						-	$M
1987	Curfew - Night Flights Eliminated	Contour Area	574,7	215,9	87,3	36,4	25,9	940,2	Sq. Mi.
		Population	1576,5	502,5	110,6	9,5	0,2	2199,3	x 1000
		Noise Units	942,0	441,9	128,3	13,4	0,3	1525,9	x 1000
		Δ NU						2106,0	x 1000
		Cost						-	$M

4.2.4 SAM and REFAN Retrofit Alternatives

These are the principal aeronautical alternatives evaluated in this study and the results are given in Table 4-5. The SAM 3D/8D retrofit alternative provides a substantial reduction in noise impact and will be shown later to provide a foundation for an even more cost-effective composite scenario of aircraft noise reduction. The estimated effectiveness of the REFAN option is, of course, much greater, but also represents the least cost-effective aeronautical alternative in terms of change in noise units per dollar cost.

4.2.5 FAR 36-10 and Composite Alternatives

One alternative evaluated for 1987 was that all new aircraft in the fleet after 1981 would be designed to meet a noise limit 10 dB below the current FAR 36 levels. The effectiveness of this is relatively small according to Table 4-6 due to the trend already underway to quieter aircraft. The composite cases considered for 1981 and 1987 show a very substantial effectiveness building on the basic noise reduction offered by the SAM 3D/8D retrofit. Note that the use of power cutback may be expected, in this case, to have a more positive benefit for the L_{dn} 65-70 band in contrast to the negative effect discussed earlier. Thus, when a source noise reduction alternative is employed which reduces the extent of the L_{dn} 65 contour, power cutback may tend to be fully effective down to this level resulting in a compounded benefit in noise reduction. This gain is not obtained for free, of course, since the population exposed to lower L_{dn} levels would experience the negative effect of power cutback tending to counterbalance the basic source noise reduction. An optimum tradeoff is suggested which would involve selection of an optimum source noise reduction and power cutback procedure to minimize noise impact.

4.2.6 Residential Noise Reduction Alternatives

Utilizing the methods developed in Section 2 to estimate impacted population and in Section 3 to estimate number of households and costs of applying noise insulation, the residential noise reduction alternative has been evaluated in detail. Tables 4-7, 4-8, and 4-9 present the results for the years 1972, 1981, and 1987 respectively.

Table 4-5

Summary Table of Results – SAM and REFAN Retrofit Cases

Year	Alternative	Factor	L_{dn} Band						
			65-70	70-75	75-80	80-85	≥ 85	Total	Units
1981	SAM 8D/3D	Contour Area	1039,8	407,7	144,8	66,6	46,1	1705,0	Sq. Mi.
		Population	2503,0	886,7	238,6	37,3	1,5	3667,1	x 1000
		Noise Units	1578,1	792,6	279,5	52,6	2,5	2702,5	x 1000
		Δ NU						690,5	x 1000
		Cost						741,8	$M
1987	SAM 8D/3D	Contour Area	1037,8	407,1	156,2	64,9	46,9	1712,9	Sq. Mi.
		Population	2763,9	983,2	268,7	43,0	1,9	4060,7	x 1000
		Noise Units	1685,4	856,8	311,7	60,6	3,2	2917,7	x 1000
		Δ NU						714,2	x 1000
		Cost						741,8	$M
1981	REFAN 8D, SAM 3D	Contour Area	450,3	209,5	97,5	34,9	23,9	816,1	Sq. Mi.
		Population	1009,7	378,6	83,9	4,56	0,06	1476,8	x 1000
		Noise Units	651,3	345,3	97,3	6,4	0,10	1100,0	x 1000
		Δ NU						2293,0	x 1000
		Cost						3051,6	$M
1987	REFAN 8D, SAM 3D	Contour Area	499,4	234,4	92,9	42,0	30,4	899,1	Sq. Mi.
		Population	1253,6	491,7	103,6	11,7	0,27	1860,9	x 1000
		Noise Units	779,6	443,3	120,1	16,5	0,45	1360,0	x 1000
		Δ NU						2271,9	x 1000
		Cost						3051,6	$M

Table 4-6

Summary Table of Results - FAR 36-10 and Composite Cases

Year	Alternative	Factor	L_{dn} Band						
			65-70	70-75	75-80	80-85	≥ 85	Total	Units
1987	FAR 36-10 (New Aircraft after 1981)	Contour Area	1160.2	419.3	165.6	64.0	47.0	1856.1	Sq. Mi.
		Population	3303.7	1080.8	327.0	48.5	2.9	4762.9	× 1000
		Noise Units	1969.6	926.9	379.3	68.3	4.8	3349.0	× 1000
		Δ NU						282.9	× 1000
		Cost						(1)	$M
1981	6°/3° Approach PCB SAM 8D/3D	Contour Area	824.8	274.4	141.0	67.7	46.6	1355.5	Sq. Mi.
		Population	1840.3	475.3	197.8	36.9	1.5	2551.8	× 1000
		Noise Units	1189.0	431.6	231.7	52.0	2.5	1906.8	× 1000
		Δ NU						1486.2	× 1000
		Cost						819.8	$M
1987	6°/3° Approach PCB SAM 8D/3D FAR 36-10(New Aircraft after 1981)	Contour Area	772.3	217.4	123.4	59.5	40.3	1212.9	Sq. Mi.
		Population	1906.2	444.7	201.4	38.0	1.6	2591.9	× 1000
		Noise Units	1192.1	403.3	233.6	53.5	2.7	1885.2	× 1000
		Δ NU						1746.7	× 1000
		Cost						819.8(1)	$M

(1) Cost unknown for development of FAR 36 - 10 dB aircraft.

Table 4-7
1972 Residential Noise Reduction Treatment Alternatives

Year	Alternative	Factor	L_{dn} Band						
			65-70	70-75	75-80	80-85	≥ 85	Total	Units
1972	Base	Contour Area	1711.0	626.7	231.0	98.7	73.6	2741.0	Sq. Mi.
		Population	5019.3	1453.9	477.1	124.2	15.0	7089.5	x 1000
		Housing Units	1859.0	484.6	159.0	37.6	5.6	2545.8	x 1000
		Noise Units	2962.1	1279.5	549.9	175.0	24.9	4991.4	x 1000
	5 dB Noise Reduction Treatment ($3,990 per Housing Unit)	Contour Area(1)	626.7	231.0	98.7	73.6	0	1030.0	Sq. Mi.
		Population(1)	1453.9	477.1	124.2	15.0	0	2070.2	x 1000
		Housing Units(1)	484.6	159.0	37.6	5.6	0	686.8	x 1000
		Noise Units	927.7	431.7	144.0	21.1	0	1524.6	x 1000
		Δ NU						3466.8	x 1000
		Cost(2)	7417.4	1933.7	634.5	150.2	22.2	10,158.0	$M
	10 dB Noise Reduction Treatment ($11,430 per Housing Unit)	Contour Area	231.0	98.7	73.6	0	0	403.3	Sq. Mi.
		Population	477.1	124.2	15.0	0	0	616.3	x 1000
		Housing Units	159.0	37.6	5.6	0	0	202.2	x 1000
		Noise Units	315.9	113.2	17.4	0	0	446.4	x 1000
		Δ NU						4545.0	x 1000
		Cost	7417.4	5539.4	1817.7	430.2	63.5	15,268.0	$M
	15 dB Noise Reduction Treatment ($20,790 per Housing Unit)	Contour Area	98.7	73.6	0	0	0	172.3	Sq. Mi.
		Population	124.2	15.0	0	0	0	139.2	x 1000
		Housing Units	37.6	5.6	0	0	0	43.2	x 1000
		Noise Units	82.7	13.6	0	0	0	96.3	x 1000
		Δ NU						4895.1	x 1000
		Cost	7417.4	5539.4	3306.3	782.5	115.5	17,161.0	$M

(1) Area, population and housing units within resultant L_{dn} band after treatment.

(2) Cost of noise reduction treatment for housing units in Base L_{dn} band.

Table 4-8

1981 Residential Noise Reduction Treatment Alternatives

Year	Alternative	Factor	L_{dn} Band						
			65-70	70-75	75-80	80-85	≥ 85	Total	Units
1981	Base	Contour Area	1257.6	481.7	178.9	76.0	52.0	2046.2	Sq. Mi.
		Population	3181.0	1100.8	314.7	54.9	3.0	4654.4	x 1000
		Housing Units	1178.1	366.9	104.9	16.64	1.1	1667.7	x 1000
		Noise Units	1973.3	972.3	365.0	77.4	5.0	3393.0	x 1000
	5dB Noise Reduction ($3990 per Housing Unit)	Contour Area(1)	481.7	178.9	76.0	52.0	0	788.6	Sq. Mi.
		Population(1)	1100.8	314.7	54.9	3.0	0	1473.4	x 1000
		Housing Units(1)	366.9	104.9	16.6	1.1	0	489.5	x 1000
		Noise Units	705.8	287.0	63.6	4.2	0	1060.7	x 1000
		Δ NU						2332.3	x 1000
		Cost(2)	4700.8	1464.1	418.6	66.4	4.4	6654.0	$M
	10dB Noise Reduction ($11,430 per Housing Unit)	Contour Area	178.9	76.0	52.0	0	0	306.9	Sq. Mi.
		Population	314.7	54.9	3.0	0	0	372.6	x 1000
		Housing Units	104.9	16.6	1.1	0	0	122.6	x 1000
		Noise Units	210.2	50.0	3.5	0	0	263.7	x 1000
		Δ NU						3129.3	x 1000
		Cost	4700.8	4194.0	1199.0	190.1	12.7	10,297.0	$M
	15dB Noise Reduction ($20,790 per Housing Unit)	Contour Area	76.0	52.0	0	0	0	128.0	Sq. Mi.
		Population	54.9	3.0	0	0	0	57.9	x 1000
		Housing Units	16.6	1.1	0	0	0	17.7	x 1000
		Noise Units	36.4	2.7	0	0	0	39.1	x 1000
		Δ NU						3353.9	x 1000
		Cost	4700.8	4194.0	2180.9	345.9	23.1	11,445.0	$M

(1) Area, population and housing units within resultant L_{dn} band after treatment.

(2) Cost of noise reduction treatment for housing units in Base L_{dn} band.

Table 4-9
1987 Residential Noise Reduction Treatment Alternatives

			L_{dn} Band						
Year	**Alternative**	**Factor**	**65-70**	**70-75**	**75-80**	**80-85**	**≥85**	**Total**	**Units**
1987	Base	Contour Area	1248.5	482.5	177.8	73.8	52.2	2034.8	Sq. Mi.
		Population	3482.5	1208.6	348.4	61.9	3.5	5104.9	x 1000
		Housing Units	1289.8	402.9	116.1	18.8	1.3	1828.8	x 1000
		Noise Units	2090.8	1043.9	404.2	87.2	5.8	3631.9	x 1000
	5 dB Noise Reduction	Contour Area[1]	482.5	177.8	73.8	52.2	0	786.3	Sq. Mi.
		Population[1]	1208.6	348.4	61.9	3.5	0	2408.7	x 1000
		Housing Units[1]	402.9	116.1	18.8	1.3	0	539.1	x 1000
		Noise Units	752.2	317.8	71.8	4.9	0	1146.7	x 1000
		Δ NU						2485.2	x 1000
		Cost[2]	5146.4	1607.4	463.4	74.8	5.2	7297.0	$M
	10 dB Noise Reduction (Only 5 dB NR for Residents in L_{dn} 65-70 Base Band)	Contour Area	177.8	73.8	52.2	0	0	303.8	Sq. Mi.
		Population	348.4	61.9	3.5	0	0	413.8	x 1000
		Housing Units	116.1	18.8	1.3	0	0	136.2	x 1000
		Noise Units	233.1	56.4	4.1	0	0	239.5	x 1000
		Δ NU						3392.4	x 1000
		Cost	5146.4	4604.8	1327.4	214.4	14.8	11,308.0	$M
	15 dB Noise Reduction (Only 5 dB NR for Residents in L_{dn} 65-70 Base Band & 10 dB NR for 70-75 Base Band)	Contour Area	73.8	52.2	0	0	0	126.0	Sq. Mi.
		Population	61.9	3.5	0	0	0	65.4	x 1000
		Housing Units	18.8	1.3	0	0	0	20.1	x 1000
		Noise Units	41.1	3.2	0	0	0	44.2	x 1000
		Δ NU						3587.7	x 1000
		Cost	5146.4	4604.8	2414.4	389.9	26.9	12,582.0	$M

[1] Area, population and housing units within resultant L_{dn} band after treatment.

[2] Cost of noise reduction treatment for housing units in Base L_{dn} band.

The basic noise impact parameters are shown again at the top of each table for convenient reference. The change in noise impact and costs to implement a 5, 10, and 15 dB increase in residential noise reduction for all homes inside the L_{dn} 65 are shown in the rest of each table. As mentioned in Chapter 3, noise reduction is not applied beyond that necessary to reduce interior noise to levels equivalent to L_{dn} 60 to 65 dB outside. Thus, for the 15 dB noise reduction alternative, only 5 dB reduction is applied to households in the base L_{dn} 65 to 70 dB band, and 10 dB to those households in the L_{dn} 70 to 75 dB band. The resulting number of people or household units in the various L_{dn} bands after treatment are the same numbers as in the baseline bands but shifted down in L_{dn} by 5, 10, or 15 dB. The costs shown in each band are the costs to treat the households located in the corresponding baseline L_{dn} bands. Note, of course, that this alternative does not change the outdoor noise level but this effect is ignored in this study. In fact, the pilot study upon which the noise reduction cost figures were based found that residents were not necessarily well pleased with a 15 dB noise reduction treatment when the outdoor level was still too high to permit comfortable use of the outdoors.[78]

This alternative is capable of providing a very high reduction in noise impact, as measured in terms of noise units. However, it is also found to have a low cost-effectiveness ratio (ΔNU/$M). Only the relocation alternative has a lower ratio. Nevertheless, there well may be optimum scenarios of noise reduction which would employ selected portions of this residential noise reduction option.

4.2.7 Relocation Alternative and Composite Noise Reduction and Relocation

The final alternative evaluated involves the relocation of people from any or all of the L_{dn} bands. As shown in Table 4-10, the changes in noise units, in this case, are the same as the noise units for the respective base cases since the resultant noise impact, after relocation, is zero. Cost is computed also on the number of households in each baseline L_{dn} band. This brute force solution is obviously the most expensive, when applied nationwide, varying from a cost of about $50 billion dollars

Table 4-10

Residential Relocation Alternatives

Year	Alternative	Factor	L_{dn} Band 65-70	70-75	75-80	80-85	≥ 85	Total	Units
1972	Relocate	Contour Area							Sq. Mi.
		Population(1)	5019.3	1403.9	477.1	124.2	15.0	7089.5	x 1000
		Housing Units(1)	1859.0	484.6	159.0	37.6	5.56	2545.8	x 1000
		Noise Units	0	0	0	0	0	0	x 1000
		Δ NU(3)	2962.1	1279.5	549.9	175.0	24.9	4991.4	x 1000
		Cost(2)	36,343	9472	3109	735	109	49,772	$M
1981	Relocate	Contour Area							Sq. Mi.
		Population	3181.0	1100.6	314.7	54.9	3.0	4654.4	x 1000
		Housing Units	1170.1	366.9	104.9	16.64	1.11	1667.7	x 1000
		Noise Units	0	0	0	0	0	0	x 1000
		Δ NU	1973.3	972.3	365.0	77.4	5.0	3393.0	x 1000
		Cost	23,033	7174	2051	325	21	32,604	$M
1987	Relocate	Contour Area							Sq. Mi.
		Population	3482.5	1208.6	348.4	61.9	3.5	5104.9	x 1000
		Housing Units	1289.8	402.9	116.1	18.8	1.3	1828.8	x 1000
		Noise Units	0	0	0	0	0	0	x 1000
		Δ NU	2090.8	1043.9	404.2	87.2	5.8	3631.9	x 1000
		Cost	25,216	7876	2270	367	25	35,754	$M
1987	Composite 5-15 dB Noise Reduction for Housing Units in 70-85 dB Bands to Reduce to 65-70 dB Relocate all in L_{dn} ≥ 85 dB Band	Contour Area	1982.6	0	0	0	0	1982.6	Sq. Mi.
		Population	5101.4	0	0	0	0	5101.4	x 1000
		Housing Units	1827.5	0	0	0	0	1827.5	x 1000
		Noise Units	3146.7	0	0	0	0	3146.7	x 1000
		Δ NU	(1055.9)	1043.9	404.2	87.2	5.8	485.2	x 1000
		Cost	0	1607	1327	390	25	3349.0	$M

(1) Population and housing units relocated (same as baseline population).

(2) Average relocation cost of $19,550 per household unit.

(3) Change in noise units relative to base for specified year indicated.

in 1972 to about $36 billion dollars in 1987 – the lower cost reflecting the estimated reduction in number of homes exposed to airport noise in the future. Again, a selected portion of this alternative might be effectively combined with other alternatives for a more cost-effective solution.

As one attempt in this direction, the last alternative considered is a combination of (1) progressive noise reduction treatment of 5 to 15 dB for all households in the L_{dn} 70 to 85 dB range so that all are reduced to exposure no greater than an L_{dn} of 65 to 70 dB, and (2) relocation of all households inside the L_{dn} 85 contour. While this alternative would clearly provide substantial relief from noise for a large number of people, it does nothing for those already residing in the 65-70 dB band – in fact, it effectively increases the population exposed to indoor level equivalent to this outdoor environment. The result is that the change in noise units for this alternative is not as great as one might expect.

4.3 General Aviation Noise Impact

The procedure for analyzing the noise impact of the general aviation fleet is discussed in Appendix H. The essential results of this effort are shown in Table 4-11 by the total contour area, impacted population, and noise units for the 1972 and 1987 base conditions along with the 1987 case with an assumed 5 dB reduction in the average noise level of the business jet fleet.

Comparing the total impact of the nation's general airports, as indicated in this table, to the figures given in the previous tables for the air carrier fleet, two dominant facts stand out:

1. The noise impact of the general aviation fleet is expected to always remain small relative to that for air carrier airports. The population inside the L_{dn} 65 contour is estimated to be about 176,000 in 1987 for general aviation airports (without any noise reduction) in contrast to the baseline conditions of 5,100,000 for air carrier airports for the same year.

Table 4-11

General Aviation Noise Impact

Year	Alternative	Factor	L_{dn} Band 65-70	L_{dn} Band 70-75	L_{dn} Band 75-80	Total	Units
1972	Base	Contour Area	141.0	46.0	25.0	212.0	Sq. Mi.
		Population	12.1	0.1	0	12.2	x 1000
		Housing Units	4.5	0.03	0	4.5	x 1000
		Noise Units	7.9	0.09	0	8.0	x 1000
1987	Base	Contour Area	346.0	117.0	60.0	523.0	Sq. Mi.
		Population	170.2	6.17	0.04	176.4	x 1000
		Housing Units	63.0	2.06	0.01	65.1	x 1000
		Noise Units	112.6	5.6	0.05	118.3	x 1000
1987	5 dB Reduction for Business Jet Fleet	Contour Area	221.0	77.0	40.0	338.0	Sq. Mi.
		Population	52.2	1.02	~ 0	53.3	x 1000
		Housing Units	19.3	0.34	~ 0	19.6	x 1000
		Noise Units	34.5	0.93	~ 0	35.4	x 1000
		Δ NU				82.9	x 1000
		Cost				376.0*	$M

*Estimated

7. However, between 1972 and 1987, the absolute value of the noise impact around general aviation airports could increase markedly unless steps are taken to regulate the noise of general aviation aircraft - especially business/executive jet aircraft.

Based on the estimated retrofit cost for treating only the business jet fleet discussed in Section 3.8, the cost of $376 M is indicated as the approximate cost of achieving the 5 dB noise reduction of the business jet fleet by 1987. This must be considered a very rough estimate at best, but tends to indicate that noise reduction alternatives for the general aviation fleet will tend to have a low cost-effectiveness when measured in terms of the change in Noise Units per dollar. A summary of cost-effectiveness of aircarrier airport noise reduction solution sets is shown below.

Summary of Cost-Effectiveness of Air Carrier Airport Noise Reduction Solution Sets

Year	Alternative	Total Population Impacted(6)	Total Noise Units(6)	Change (Δ) Noise Units(1)	Total Cost	Cost-Effectiveness
		X1000	X1000	X1000	$M	ΔNU(1000) / $M
1972	Base	7087.5	4921.4	-	-	-
1987	Base	5104.9	3631.9	-	-	-
Operational	Power Cutback	5478.3	3790.7	(158.8)	-	-
	4° Approach	4914.0	3443.3	188.6	-	-
	6°/3° Approach	4581.9	3286.9	345.0	78.0	4.42
	Curfew A(2)	2491.5	1748.6	1883.3	-	-
	Curfew B(3)	2199.3	1525.9	2106.0	-	-
Aeronautical	SAM 3D/8D	4060.7	2917.7	714.2	741.8	0.96
	REFAN 8D/SAM 3D	1860.9	1360.0	2271.9	3051.6	0.74
	FAR 36-10(4)	4762.9	3349.0	282.9	-	-
	Composite(5)	2591.9	1885.0	1746.9	819.8	2.13
Receiver	Residential Noise Red. dB -5	2408.7	1146.7	2485.2	7297.0	0.34
	-10	413.8	259.5	3372.4	11,308.0	0.30
	-15	65.4	44.2	3587.7	12,583.0	0.29
	Relocate 85	5101.4	3626.1	5.8	25.4	0.23
	All Inside 75	4691.1	3134.7	497.2	2662.4	0.19
	L_{dn} 65	0	0	3631.9	35,754.0	0.10

Notes:
(1) ΔNU relative to base for year indicated
(2) Night flights rescheduled to day time (7AM - 10PM)
(3) Night flights eliminated
(4) FAR 36-10 for new aircraft after 1981
(5) 6°/3°, PCB, SAM 3D/8D and FAR 36-10 for new aircraft after 1981
(6) Inside the L_{dn} 65 contour at all the nation's air carrier airports

5.0 CONCLUSIONS AND RECOMMENDATIONS

Following is a summary of the results of this study in terms of the effectiveness and associated costs for the various noise abatement solution sets. Effectiveness is defined by the potential reduction in the size of the noise-impacted contour area and affected population as related to certain "baseline" or no action condition. A "baseline" condition was developed for each time period in question, i.e., 1972, 1981, and 1987.

Baseline Comparisons, Air Carrier Operations

Comparing the total 1972 baseline national contour area with the 1981 contour area, one can conclude that the latter has been reduced by approximately 30 percent. This is the result of the normal introduction of quieter aircraft into the fleet mix. Comparisons of the 1981 baseline with the 1987 baseline indicates an insignificant reduction in the contour area with a slight increase (approximately 8 percent) in the number of people exposed. This is due to the assumed 10 percent increase in the population growth rates over that period. The lack of change in the contour area merely reflects the counterbalance between the increase in the number of quieter aircraft and the increase in the projected volume of operations.

Costs: – Not applicable.

Power Cutback (PCB) Alternative

Generally speaking, a consistent increase was shown in this study for the area and the number of people impacted within the L_{dn} 65 dB contour when PCB is applied. This is primarily due to an increase in the noise-impacted area of the L_{dn} 65 to 70 dB zone which is caused by the tendency for noise to increase after a power cutback operation is completed. At the largest airports, however, there is a significant decrease in the population exposed to an L_{dn} 70 dB and above. This does not hold true for the smaller category of airports. It is clear that PCB is an airport specific alternative and is not equally beneficial at all airports. The anomalous result obtained for PCB in this study can also be attributed, in part, to the use of the single-runway AVport model which tends to accentuate the length of the L_{dn} 65 dB contour beyond the average length that would occur in actual practice.

Costs: – PCB is assumed to be a no-cost alternative.

Modified Approach Glide Slope Alternative

The 4° and 6°/3° approaches offer only a small benefit in reducing the impact area when applied on a national scale. Major benefits, however, would be derived when utilized at airports which have been identified as approach noise dominated facilities such as LAX. The 4° glide slope is less beneficial for areas with an L_{dn} below 70 dB, while the 6°/3° approach is of greater benefit at the lower L_{dn} values.

Costs: –	On-board electronics for 2087 aircraft in service during 1975	$73 M ($35,000/aircraft)
	ILS/DME installations for 100 runways	$ 5 M ($50,000/runway)

Curfew Alternatives

The two curfew alternatives (eliminating all night operations and rescheduling all night operations to daytime) demonstrated an approximately 50 percent reduction in the overall impact. However, essentially no difference is demonstrated between the two alternatives. Simply removing the weighted night operations far outweighs any equivalent increase in the daytime activity levels.

Costs: – Due to the highly complex economic interrelationships, cost analysis for the curfew alternative was beyond the scope of this study.

Retrofit Alternatives

SAM 3D/8D provides a substantial reduction in the impact area (in the order of 16 percent). Although REFAN provides an even greater reduction (in the order of 23 percent), it is the least cost-effective of the two major aeronautical alternatives.

Costs: – Retrofit costs in 1975 dollars are identified below.

Summary of Retrofit Costs, 1975 Dollars

Retrofit Alternative	Initial Investment $M	Operating Costs $M	Total $
SAM 8D	256.7	3.8	283.4
SAM 3D	322.3	21.0	458.4
SAM 8D/3D	579.0	24.8	741.8
REFAN 8D	1,711.3	125.8	2,893.2
REFAN 8D, SAM 3D	2,033.3	146.8	3,051.6

FAR 36-10

Since this alternative was only applied to new production aircraft introduced into the fleet, it showed relatively little effect due to the small number of aircraft which were assumed to realistically reflect this condition by 1987.

Costs: — No cost data were available.

Composite Alternatives

The combinations of 6°/3° approach, PCB, and SAM 8D/3D in 1981 and 6°/3°, PCB, SAM 8D/3D, and FAR 36-10 for 1987 show a substantial benefit in reducing the impact area, i.e., in the order of 30 percent (for 1981) and 40 percent (for 1987) respectively.

Costs: — Cost data incomplete.

Residential Noise Reduction Alternative

The application of noise reduction treatment of residential houses at the identified levels of 5, 10, and 15 dB is a very significant noise reduction alternative, i.e., in the order of 25, 85, and 93 percent respectively in 1972.

Costs: — Noise reduction treatment is a low cost-effectiveness solution. Shown below are the estimated total costs for insulation at 5, 10, and 15 dB for the three time periods as compared to the baseline condition. It should be emphasized, however, that a complete evaluation of noise reduction treatment would include its application in conjunction with other more cost-effective alternatives.

Summary of Costs of Noise Reduction Treatment
for all Residents inside L_{dn} 65 Contour

Reduction, dB	Insulation Costs in $M (1975 Dollars)		
	1972	1981	1987
5	10,158	6,654	7,297
10*	15,268	10,297	11,308
15*	17,161	11,445	12,582

Treatment limited to achieve minimum L_{dn} of 60 dB.

Relocation Alternative

This alternative is even less cost-effective than the noise treatment alternatives.

Costs: — Removing all residential impact land falling within at least the L_{dn} 65 dB, the cost ratios vary from $50 billion in 1972 to $36 billion in 1987.

General Aviation Alternative

As a result of our analysis, it became clear that although the impact from general aviation aircraft is very small compared to civil air carrier operations, the absolute value of noise could increase markedly between 1972 and 1987 unless steps are taken to regulate these aircraft, especially the business jets. This is largely due to the projected increase in the number of general aviation operations. The only abatement alternative applied in this study was to simply reduce the levels of all business jets by 5 dB. This resulted in an overall impact area reduction of 36 percent in 1987. This is still significantly above the impact identified for the base year 1972.

Costs: – The estimated cost to reduce the noise levels of all candidate business jet aircraft by 5 dB in 1987 is about $376M. A rough estimate of costs to reduce the noise from propeller aircraft (replacing the two-blade propellers with three-blade propellers on all new production aircraft) is $95M. These are obviously very low cost-effective noise reduction measures for this market.

Fuel Costs

Due to the complex economics and interrelationships of the aviation system, a detailed analysis of fuel cost implications of the aircraft noise reduction alternatives was beyond the scope of this study.

Recommendations

The following areas need to be evaluated in more detail in order to complete the analysis of feasible noise abatement solution sets for the reduction of airport/aircraft noise impact on the nation.

- Demonstrate the feasibility of optimizing the PCS and approach glide slope procedures as a function of airport specific requirements, benefits, and disbenefits.
- Demonstrate in detail the costs and benefits of curfews on the total air carrier system.
- Evaluate other aircraft noise reduction alternatives which have or are to be proposed by EPA, such as the more detailed FAR 36 reduction rule or the fleet noise rule.
- Develop and demonstrate the cost-effectiveness of minimum cost solution for combinations of noise abatement alternatives, i.e., optimum combinations of source, operational, and receiver noise abatement solution sets.
- Demonstrate the impact of military, helicopter, and seaplane airports on a national scale.

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APPENDIX A

AIRCRAFT MIX AND ACTIVITY DATA FOR AVPORTS I, II, AND III

Table A-1 indicates the grouping of specific aircraft types into generalized categories and shows which aircraft were considered in the operations mix of each AVport for the years 1972, 1981, and 1987.

Tables A-2, A-3, and A-4 give the operations mix for AVport I. Tables A-5 and A-6 give the same data for AVports II and III respectively.

Table A-1

Aircraft Category/Type Mix for AVports I, II and III

Aircraft Category/Type	AVport I			AVport III		AVport II		
	1972	1981	1987	1972	1981	1972	1981	1987
2 Engine SR NB:								
DC-9	X	X	X	X	X	X	X	X
DC-9-30 (GN)		X	X					
B737-100	X			X				
B737-200	X	X	X	X	X	X	X	X
B737-200 (GN)		X	X					
STOL, F28, 100 PAX		X	X					
2 Engine MR NB:								
BAC-111	X					X		
2 Engine SR WB:								
A300B		X	X		X			
2 Engine Turboprop								
F-27				X	X	X	X	X
3 Engine MR NB:								
B727-100	X	X	X	X		X		
B727-200	X	X	X	X	X	X	X	X
B727-200 (GN)		X	X					
3 Engine MR WB:								
DC-10-10	X	X	X					
DC-10-30		X	X					
L-1011	X	X	X					
4 Engine LR NB:								
B707-320 B/C	X	X	X	X				
B707-320 B(GN)		X	X					
B707-120B	X							
B707-120/320	X							
B720	X							
B720B	X			X				
VC-10	X							
DC-8-55/61/63	X	X	X					
DC-8-30	X							
4 Engine M-LR WB:								
B747-100	X							
B747 Stretch		X	X					
4 Engine MR WB:								
B747-200B		X	X					

Table A-2

AVport I 1972 Mix Data

Aircraft	Day/ Night	Arrivals	Departures by Stage Length, n mi					
			0-500	500-1000	1000-1500	1500-2500	2500-3500	3500-4500
2-Engine Short Range Narrow Body	D	65.61	49.48	16.13				
	N	8.31	5.26	2.42				
2-Engine Medium Range Narrow Body	D	5.04	5.0	0.04				
	N	0.39	0.39	0				
3-Engine Medium Range Narrow Body	D	80.58	20.61	34.9	7.07	18.0		
	N	11.97	2.83	5.56	1.58	2.0		
3-Engine Medium Range Wide Body	D	4.6	0.6	1.57	0.65	1.48	0.3	
	N	0.77	0.04	0.6	0.04	0.09	0	
4-Engine Long Range Narrow Body	D	50.6	15.92	10.75	6.50	10.91	4.78	1.74
	N	13.52	4.22	3.26	0.78	4.04	1.05	0.17
4-Engine Medium-Long Range Wide Body	D	7.97	1.09	0.61	1.09	2.74	2.44	
	N	0.75	0.09	0.09	0.09	0.48	0	

Table A-3

AVport I 1981 Mix Data

Aircraft	Day/ Night	Arrivals	Departures by Stage Lenght, n mi					
			0- 500	500- 1000	1000- 1500	1500- 2500	2500- 3500	3500- 4500
2-Engine Short Range Narrow Body	D	69,72	53,04	16,51	0,17			
	N	6,69	4,56	2,13	0			
2-Engine Short Range Wide Body	D	13,88	7,78	6,1				
	N	1,73	0.73	1,0				
3-Engine Medium Range Narrow Body	D	93,92	54,31	25,04	12,13	2,44		
	N	12,9	6.87	3.41	2,22	0,4		
3-Engine Medium Range Wide Body	D	32,11	9,22	6,24	3,37	10,65	2,59	0,04
	N	7,04	1,13	2,31	1,51	1,75	0,32	0,02
4-Engine Long Range Narrow Body	D	22,38	7,87	6,04	1,61	4,56	1,22	1,08
	N	5.12	1,69	1,61	0,13	1,39	0,17	0,13
4-Engine Medium-Long Range Wide Body	D	22,75	2,09	3,39	3,26	8,87	3,31	1,83
	N	4,48	0,57	0,74	1,47	1,44	0,26	0

Table A-4

Airport 1 1987 Mix Data

Aircraft	Day/Night	Arrivals	Departures by Stage Length, n mi					
			0-500	500-1000	1000-1500	1500-2500	2500-3500	3500-4500
2-Engine Short Range Narrow Body	D	71.92	54.61	17.3	0.01			
	N	6.43	4.61	1.82	0			
2-Engine Short Range Wide Body	D	20.64	11.67	8.97				
	N	2.25	0.99	1.26				
3-Engine Medium Range Narrow Body	D	108.53	63.2	29.34	13.52	2.47		
	N	12.79	6.88	3.17	2.31	0.43		
4-Engine Long Range Narrow Body	D	21.02	7.31	5.79	1.04	4.57	1.35	0.96
	N	4.79	1.87	1.18	0.3	1.27	0.17	0
4-Engine Medium-Long Range Wide Body	D	23.5	2.11	3.77	3.31	8.92	3.47	1.92
	N	4.12	0.56	0.86	1.45	1.39	0.86	0

Table A-5

AVport II 1979 Mix Data

Aircraft	Day/ Night	Arrivals	Departures by Stage Length, n mi							
			0-500	500-1000	1000-1500	1500-2500	2500-3500	3500-4500	4500-5500	Over 5500
2-Engine Medium Range Narrow Body	D	0.25	0.25							
	N	0	0							
2-Engine Short Range Narrow Body	D	3.4	3.4							
	N	1.15	1.15							
3-Engine Medium Range Narrow Body	D	1.0	1.0							
	N	0.25	0.25							
2-Engine Turboprop	D	2.66	2.66							
	N	1.44	1.44							

AVport II 1981 Mix Data

Aircraft	Day/ Night	Arrivals	Departures by Stage Length, n mi							
			0-500	500-1000	1000-1500	1500-2500	2500-3500	3500-4500	4500-5500	Over 5500
2-Engine Short Range Narrow Body	D	4.38	4.38							
	N	1.37	1.37							
3-Engine Medium Range Narrow Body	D	1.0	1.0							
	N	0.25	0.25							
2-Engine Turboprop	D	3.2	3.2							
	N	1.8	1.8							

AVport II 1987 Mix Data

Aircraft	Day/ Night	Arrivals	Departures by Stage Length, n mi							
			0-500	500-1000	1000-1500	1500-2500	2500-3500	3500-4500	4500-5500	Over 5500
2-Engine Short Range Narrow Body	D	4.73	3.84							
	N	1.48	1.48							
3-Engine Medium Range Narrow Body	D	1.2	1.2							
	N	0.3	0.3							
F27 2-Engine Turboprop	D	3.68	3.68							
	N	2.07	2.07							

Table A-6

AVport III (Mid-Range) 1972 Mix Data

Aircraft	Day/ Night	Arrivals	Departures by Stage Length, n mi 0-500	500-1000	1000-1500	1500-2500	2500-3500	3500-4500	4500-5500	Over 5500
4-Engine Long Range Narrow Body	D	1.5	0.5			1.0				
	N	0	0			0				
2-Engine Short Range Narrow Body	D	16.5	13.5	3.0						
	N	2.0	2.0	0						
3-Engine Medium Range Narrow Body	D	6.5	4.5	1.0	0.5	0.5				
	N	0.5	0.5	0	0	0				
2-Engine Turboprop	D	5.5	5.5							
	N	1.0	1.0							

AVport III (Mid-Range) 1981 Mix Data

Aircraft	Day/ Night	Arrivals	Departures by Stage Length, n mi 0-500	500-1000	1000-1500	1500-2500	2500-3500	3500-4500	4500-5500	Over 5500
2-Engine Short Range Narrow Body	D	20.0	15.5	4.5						
	N	3.0	3.0	0						
2-Engine Short Range Wide Body	D	7.0	4.0	3.0						
	N	0.5	0.5	0						
3-Engine Medium Range Narrow Body	D	3.0	1.5	1.5						
	N	0	0	0						
2-Engine Turboprop	D	7.0	7.0							
	N	1.5	1.5							

APPENDIX B

COST OF RESIDENTIAL NOISE REDUCTION TREATMENT – AN UPDATE OF LAX STUDY

1. INTRODUCTION

The data from the 1969 study by Wyle Research on soundproofing 20 homes around Los Angeles International Airport[28] has been reviewed and updated to provide the following:

a. A standard conversion of the original noise reduction data, expressed in terms of the incremental change (ΔNR_{SIL}) in noise reduction measured by Speech Interference Level (NR_{SIL}), to the corresponding increment in A-weighted noise levels (ΔNR_A).

b. A standard accounting for the additional cost of treating rooms with open-beam ceilings.

c. A standard updating of the cost data to current (October 1975) values to account for inflation since the 1969 data of the original work.

Although other studies on costs of residential noise reduction have been made (see summary in Reference 27), the Wyle study appeared to be the most complete for which cost details were conveniently available. Thus, this update is limited to this one study.

2. CONVERSION OF ΔNR_{SIL} TO ΔNR_A

The conversion process involves translating both the before-and-after treatment noise reduction in SIL to their corresponding values of noise reduction in A-weighted levels and then taking the difference between these as the increment in A-weighted noise reduction.

Before Treatment NR_{SIL} and NR_A

The before-treatment reference condition was for windows open 6 inches. The average decrease in SIL noise reduction, due to opening windows, averaged over all the homes studied, was 4.1 dB. The before-treatment noise reduction in SIL, for each of the three groups of homes, with windows open and closed, is summarized below.[28]

Noise Reduction Before Treatment, dB

Stage[4]	Number of Homes	NR_{SIL}[1]	Δ[2]	NR_{SIL}[3]
I	6	30.1	-4.1	26.0
II	11	29.9	-4.1	25.8
III	3	28.0	-4.1	23.9

[1] Average for windows closed

[2] Decrease due to open windows (average for all 20 homes)

[3] Average for windows open

[4] The three stages of noise reduction treatment carried out in the LAX study.

The method of converting NR_{SIL} to NR_A is based on the use of data reported in Reference 27 on 18 rooms in five houses where both values for NR were measured at various stages of treatment. These data, summarized in Figure B-1, provide the following regression lines for takeoff and approach conditions of jet aircraft.

For takeoff $\quad NR_A = 0.74(NR_{SIL}) + 3.90 \quad$, dB $\qquad$ (1)

For approach $\quad NR_A = 0.99(NR_{SIL}) - 0.86 \quad$, dB $\qquad$ (2)

Averaging these two equations gives one average expression for takeoff or approach:

$$NR_A = 0.85\, NR_{SIL} + 1.86 \quad , \text{dB} \qquad (3)$$

Very nearly the same result is obtained from analysis of the Wyle/LAX data using an average aircraft spectrum (takeoff and landing) at slant distances of 1000 to 4000 feet. Due to the wider range of values provided in Reference 27, the latter is used here to convert NR_{SIL} to NR_A.

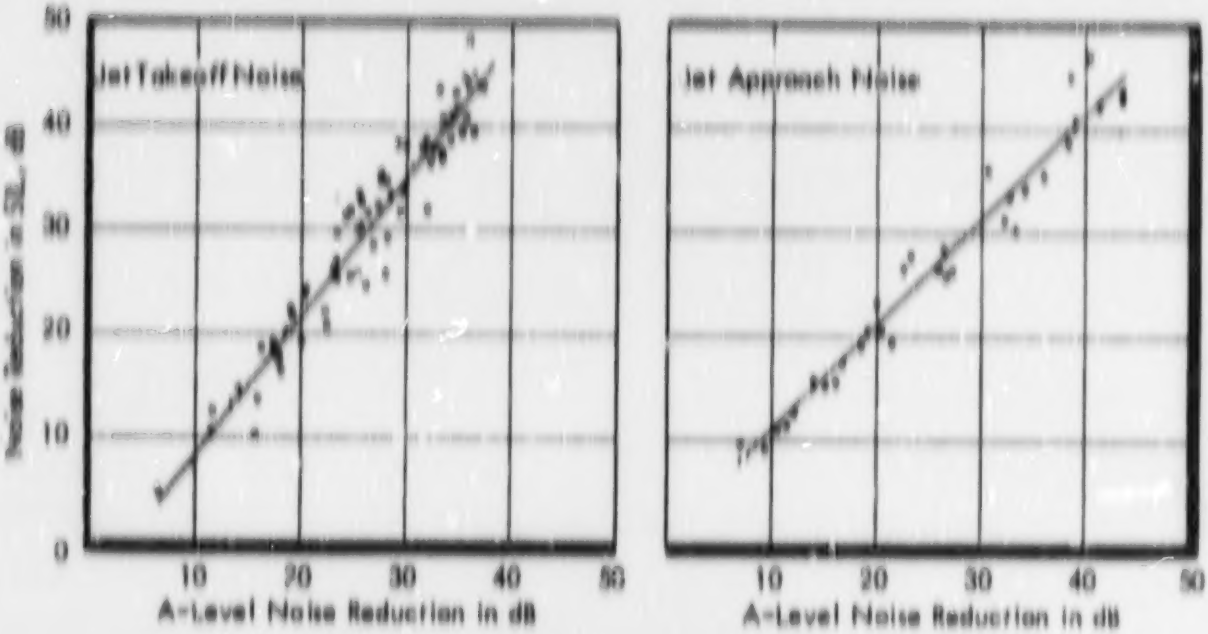

Figure B-1. Correlation of House Noise Attenuation Measures - SIL Versus dBA (From Reference 27)

After-Treatment NR_{SIL} and NR_A

Applying equation (3) to the last column in the preceding table provides the estimated before-treatment noise reduction in A-weighted levels. The increment in NR_{SIL} is then added, after treatment, and new NR_A values computed, again with equation (3). These are then compared to the before-treatment values to obtain the increment (ΔNR_A) in noise reduction of A-weighted values. This process is summarized in the following table.

Conversion of Wyle/LAX Noise Reduction Data to A-Weighted Values

Stage	Before Treatment, dB		After Treatment, dB			
	NR_{SIL} (1)	NR_A (2)	ΔNR_{SIL} (3)	NR_{SIL}	NR_A (2)	ΔNR_A
I	26.0	24.0	7.0	33.0	29.9	5.9
II	25.8	23.8	9.5	35.3	31.9	8.1
III	23.9	22.2	17.7	41.6	37.2	15.0

(1) Windows open 6 inches.

(2) Computed from NR_{SIL} and equation (3).

(3) Increase in SIL noise reduction due to treatment.

3. COST INCREMENT FOR OPEN BEAM CEILING ROOMS

There were 5 out of the 11 Stage II treatment homes in the LAX study with one or more rooms with open-beam ceilings. These required additional treatment not required in conventional homes with a closed attic. The actual experienced additional cost for this condition was $2.28 per square foot of open beam ceiling area in Stage II treatment homes. The estimated cost for Stage III treatment homes was $2.70.[28] Based on the actual number of rooms encountered in the Stage II treatment sample, the average cost for this Los Angeles sample was $0.50 per square foot of residential floor area. In other words, only about 22 percent ($0.50/$2.28) x 100 of the rooms had open beam ceilings. It is assumed that for a national sample of homes, only one-half as many open-beam ceiling rooms would be encountered. Thus, for the (national) average Stage II treatment home, the added cost for the occasional open-beam ceiling is assumed to be 1/2 x $0.50 or $0.25/square foot of residential floor area. For Stage III treatment homes, the cost increment is increased by the ratio 2.70/2.28 to $0.30/square foot of residential floor area.

Adding these corrections to the basic cost figures cited in the report for rooms without beamed ceilings gives the following corrected cost values (in 1969 dollars).

Correction of 1969 Cost Data for Open Beam Ceiling Houses
(Dollars Per Square Foot)

Stage	Basic Cost	Increment for Open Ceilings	Revised Average Cost
I	$2.10	$0(1)	$2.10
II	$3.15	$0.25	$3.40
III	$8.20	$0.30	$8.50

(1)Ceiling treatment not applied for Stage I

4. UPDATING OF DATA TO REFLECT INFLATION

The preceding data were based on labor and material costs experienced in 1969. To allow for inflation, the Homeowner's Cost Index will be used.* This index is given below for the years 1969 to October 1975.

Period	1969	1970	1971	1972	1973	1974	1975(October)
Homeowner's Cost Index	116.0	128.5	133.7	140.1	146.7	163.2	183.9

Applying the ratio 183.9/116 = 1.585 to the preceding cost figures and correlating these to the corresponding noise reduction performance gives the following values.

Stage	ΔNR_A	Cost(1) (October 1975) $ per Square Foot
I	5.9	3.33
II	8.1	5.39
III	15.0	13.47

(1)Including open-beam ceiling adjustment

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*This cost index is somewhat conservative as an indicator of inflation of only labor and material costs since it also reflects additional costs of taxes, insurance, maintenance, etc. However, the increase since 1969 represents an annual inflation rate of 8 percent over 6 years - a reasonable value for the effect of inflation.

Finally, for the sake of convenient specification of costs in 5 dB increments of added noise reduction, these figures have been fitted with a cubic expression to give the following cost estimator in 1975 (October) dollars and corresponding table of values for 5, 10, and 15 dB increments in A-weighted noise reduction.

Residential Noise Reduction Treatment Cost in 1975 Dollars

$$\text{Cost } (\$/\text{ft}^2) = 0.2293(NR_A) + 0.0647(NR_A)^2 - 0.00134(NR_A)^3$$

NR_A dB	Cost $ per Square Foot
5	2.60
10	7.42
15	13.47
20	19.75

Figure B-2 shows the revised (1975 dollars) data from the above table compared to the original data from the 1969 study. Note that extrapolation of these figures beyond an incremental increase of 20 dB is not practical. The total resulting noise reduction for the average house would be 30 to 40 dB, depending on the region and climate. These revised values, applicable to regional costs for the Los Angeles area, are adjusted to national average values in Table 3-1 in Section 3.

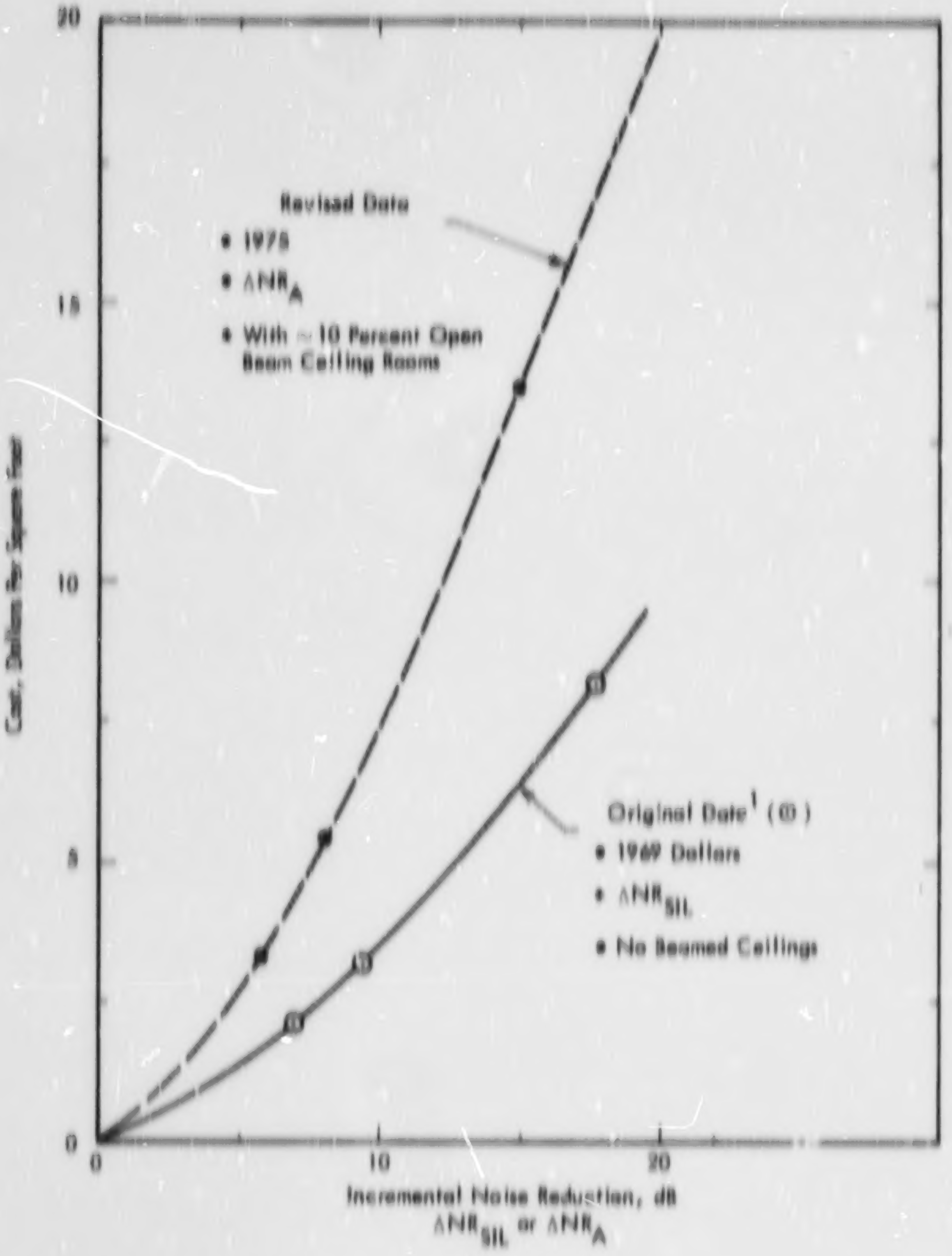

Figure B-2. Comparison of Original and Revised Cost Data for Residential Noise Reduction (Valid for Los Angeles Area Only)

APPENDIX C

NOISE EXPOSURE LEVEL IN dB VERSUS SLANT DISTANCE AND THRUST FOR AIR CARRIER AIRCRAFT

The following table provides a key to the aircraft type and noise curve number listed in Table C-2.

Table C-1

Key to Noise Tables

Noise Curve Number	Aircraft Type
1972 Data	
2	B707, DC-8 (TF)
3	Caravelle
4	DC-8 (TJ)
6	DC-9
7	DC-10
8	L-1011
9	B707, CV-880 (TJ)
10	B727
11	B720 (TJ)
12	B737
13	B747-100
15	A 300B
Future Noise Data	
3R	B707, DC-8 (SAM)
4R	STOL
9R	B727 (SAM)
11R	B737 (SAM)
13R	B747-200
16	DC-9 (SAM)

Table C-2

Noise Exposure Level in dB Versus Slant Distance for Air Carrier Aircraft

1972 Noise Data

No.[1]	F_n/δ[2]	200	400	600	1000	2000	4000	6000	10,000
		Slant Distance, Feet							
2	15250.	118.63	113.90	110.89	106.34	99.51	91.58	87.57	81.92
2	11990.	116.13	111.60	108.49	103.96	96.41	88.08	83.47	77.72
2	8830.	115.03	110.70	107.59	103.14	95.21	85.08	80.57	75.92
2	5840.	113.63	109.10	106.09	101.44	93.41	82.48	78.37	70.22
2	3630.	110.83	106.20	103.19	98.88	90.81	80.18	72.97	63.22
3	12200.	121.46	119.58	117.89	114.06	107.58	99.10	93.11	89.38
3	9000.	112.36	110.08	108.09	104.16	96.20	86.70	79.11	72.44
3	6000.	109.76	107.38	105.19	101.76	93.78	83.70	76.11	67.88
4	14700.	127.07	123.94	121.22	117.25	110.82	103.09	97.97	91.70
4	10000.	122.17	117.44	114.52	109.85	102.82	95.29	90.47	85.90
4	6000.	114.97	111.04	108.12	101.85	96.42	87.40	82.77	75.70
4	4000.	111.97	107.84	104.72	99.85	90.04	84.49	76.37	70.84
5	12000.	118.56	116.58	110.49	107.[illegible]	102.38	97.10	93.91	89.88
5	10000.	114.16	109.28	106.49	102.76	98.18	92.7	89.11	84.38
5	8000.	110.96	105.88	102.89	99.06	94.08	88.70	84.71	79.88
5	6000.	108.36	102.98	99.99	95.76	90.28	83.80	79.81	74.98
5	5000.	107.46	101.78	98.69	94.36	88.58	81.40	76.51	71.58
5	4000.	105.58	100.78	97.29	92.88	88.18	78.30	73.21	67.58
7	30800.	112.16	106.58	103.10	98.26	92.18	85.80	80.61	73.88
7	20800.	109.98	103.98	100.49	95.96	89.18	80.60	75.51	69.08
7	14800.	107.68	101.58	97.79	92.66	85.08	75.60	70.51	65.98
7	11900.	106.76	100.18	96.29	90.56	82.58	73.10	68.01	61.28
7	9200.	103.16	99.05	95.29	89.26	80.28	70.[illegible]	65.41	57.08
8	35000.	111.16	106.58	103.49	99.06	92.68	85.30	80.91	77.58
8	25700.	109.15	104.28	101.09	96.86	90.28	83.10	78.81	72.78
8	15800.	106.28	101.18	97.79	93.26	86.58	79.30	74.81	68.78
8	12700.	104.06	98.98	95.79	91.06	84.28	76.80	72.31	66.18
8	9500.	101.86	96.48	93.29	89.06	82.28	74.90	70.11	65.58
8	7700.	100.28	93.38	92.47	87.85	81.38	73.80	67.01	62.10
9	14750.	129.77	125.14	121.78	117.35	110.58	103.69	99.97	93.90
9	12000.	123.57	119.64	116.38	112.05	105.98	98.19	93.60	88.40
9	10000.	119.67	115.34	112.38	107.85	101.38	94.33	90.17	85.31
9	5500.	113.17	108.64	105.48	100.55	93.33	85.99	80.47	73.41

1972 Noise Data (Continued)

		Slant Distance, Feet							
No.$^{(1)}$	$F_n/\delta^{(2)}$	200	400	600	1000	2000	4000	6000	10,000
10	13050.	122.78	118.13	115.43	111.86	106.48	100.50	96.71	90.58
10	9800.	116.16	111.58	108.79	104.86	99.15	92.40	88.21	82.18
10	7600.	112.06	106.98	103.89	99.46	93.56	87.10	83.01	76.88
10	5300.	109.86	104.38	100.89	95.86	89.08	82.10	77.71	71.98
10	4400.	108.96	103.58	99.89	94.96	87.78	80.40	76.21	70.48
10	3500.	108.76	102.98	99.19	94.16	86.38	78.80	74.71	67.88
11	10700.	125.97	120.88	117.62	113.25	107.02	100.69	96.57	91.50
11	8000.	120.57	115.88	112.82	108.45	102.82	96.19	92.27	87.10
11	6000.	115.27	110.74	107.72	103.35	97.02	90.19	85.97	80.60
11	4220.	111.17	106.38	102.92	98.15	91.42	84.09	79.37	73.40
12	12190.	119.78	114.93	112.29	108.28	102.08	95.90	91.81	85.58
12	9480.	112.88	107.78	104.79	101.08	95.38	88.70	84.51	78.78
12	6150.	108.96	103.58	99.89	94.96	88.68	82.50	78.01	72.18
12	5050.	107.96	102.48	98.89	93.76	85.08	78.10	73.81	67.98
12	3900.	106.78	101.58	97.59	92.88	84.88	76.50	72.11	66.88
13	33800.	121.16	115.98	112.89	108.56	101.58	93.80	89.21	82.78
13	21100.	118.76	113.98	110.74	106.18	98.68	90.00	84.61	77.48
13	15000.	116.06	110.88	107.49	102.88	95.18	86.40	81.11	75.08
13	12300.	114.86	108.88	105.59	100.96	93.48	84.40	78.81	71.28
13	9200.	110.56	105.48	102.19	97.56	90.38	82.00	76.51	69.48
13	7800.	108.78	103.98	100.97	96.08	88.38	79.89	75.11	65.98
15	30800.	110.36	104.78	101.39	96.88	90.38	81.68	76.61	72.08
15	20800.	108.16	102.18	98.69	94.16	87.38	79.80	73.71	67.28
15	14600.	105.86	99.78	95.99	90.86	83.28	73.80	68.71	62.18
15	11900.	104.96	98.38	94.49	88.76	80.78	71.50	66.21	59.48
15	9200.	103.36	97.28	93.89	87.88	78.48	68.70	63.51	57.28

Future Noise Data

No.(1)	F_n/δ(2)	Slant Distance, Feet 200	400	600	1000	2000	4000	6000	10,000
5 R	13950.	111.65	107.40	104.79	101.64	96.91	90.64	86.47	80.62
5 R	11950.	107.65	103.60	100.99	97.58	92.41	87.08	82.97	76.92
5 R	9670.	103.01	99.50	96.69	93.08	87.91	81.43	78.07	72.92
5 R	9150.	100.21	95.90	93.19	89.68	84.41	78.48	74.57	69.72
5 R	4950.	96.61	91.50	88.19	84.08	78.31	71.08	67.87	62.62
6 R	8600.	109.06	106.88	103.99	100.46	95.08	89.00	85.11	79.07
6 R	5900.	108.56	104.08	100.09	94.66	86.88	79.80	75.01	68.68
6 R	4200.	106.96	97.96	93.19	86.86	77.18	67.70	63.01	56.78
9 R	12800.	121.86	116.08	114.09	110.56	105.38	97.70	95.41	90.14
9 R	10000.	118.46	109.98	107.19	103.66	98.18	91.70	87.31	81.56
9 R	8200.	110.46	105.98	103.09	99.16	93.18	86.90	82.81	76.88
9 R	5400.	104.96	100.18	97.69	91.96	88.08	81.20	77.01	71.58
9 R	4900.	103.66	99.08	96.29	92.46	86.58	79.50	75.41	69.58
9 R	3800.	101.30	96.80	93.99	89.96	82.88	77.70	73.61	67.78
11 R	13000.	123.76	117.88	114.99	111.16	105.18	98.60	93.91	87.98
11 R	12770.	120.76	116.18	113.39	109.56	103.78	97.20	92.61	87.50
11 R	8220.	110.46	105.78	102.89	99.06	93.98	87.20	82.61	76.08
11 R	8120.	104.46	100.18	97.39	93.56	87.98	81.40	77.51	70.88
11 R	5570.	104.16	98.48	95.29	91.26	85.88	79.70	75.41	71.78
11 R	4150.	101.96	95.88	92.19	88.60	82.80	76.50	72.81	67.68
15 R	55500.	118.76	111.78	108.59	103.56	98.48	91.80	87.01	80.78
15 R	41100.	115.96	110.19	106.99	102.96	95.48	89.50	85.01	79.18
15 R	24700.	112.16	107.19	103.89	99.66	92.98	85.80	81.61	75.28
15 R	15500.	108.16	103.18	99.89	95.36	88.28	81.80	76.51	70.58
15 R	13400.	105.86	101.08	94.59	94.26	87.40	80.20	75.41	64.98
15 R	8850.	103.16	99.78	96.59	92.26	85.88	78.20	73.81	65.78
16	11880.	117.96	113.98	111.29	107.96	101.68	95.50	91.01	84.58
16	9750.	112.16	107.68	104.79	100.96	95.58	89.20	85.01	79.58
16	6260.	105.16	100.98	98.09	94.36	88.68	82.30	78.21	72.28
16	5060.	102.56	97.08	93.99	89.96	84.38	78.20	73.81	67.78
16	4010.	102.10	96.43	92.59	87.46	81.48	75.20	70.91	[illegible]

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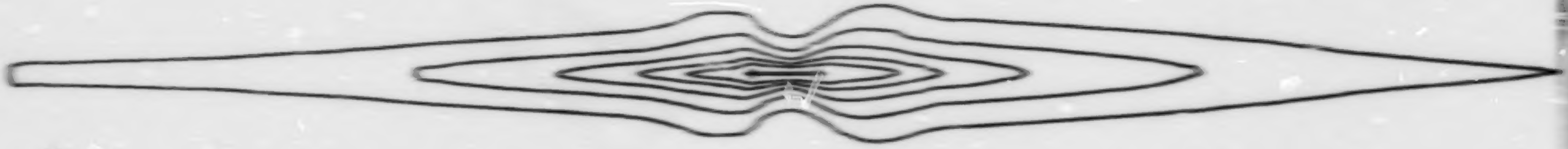
(1) Noise curve number (see Table C-1 for identification of aircraft).

(2) Corrected net thrust in lbs, where δ = ratio of pressure at altitude to pressure at sea level.

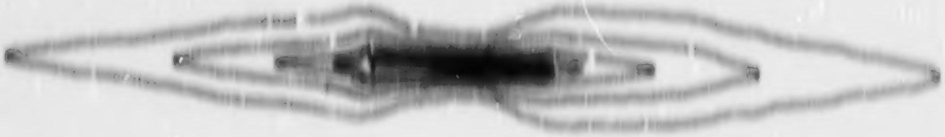
APPENDIX D

L_{dn} NOISE CONTOURS FOR AVPORTS I, II, AND III

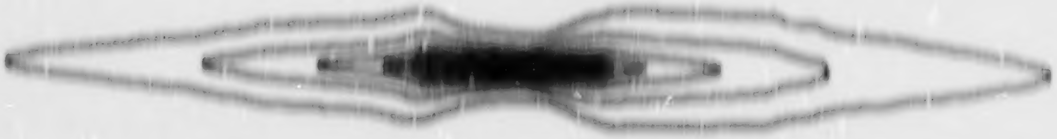


Scale: 0 10,000'

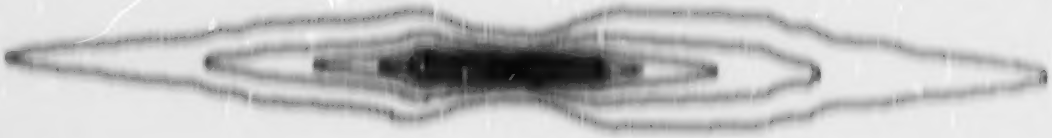
Figure D-1. Airport I Baseline 1972 – L_{dn} 65, 70, 75, 80 and 85 Contours



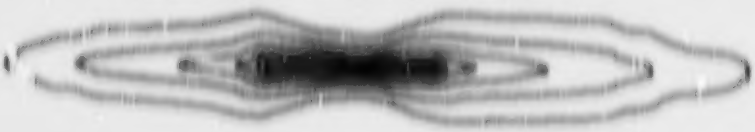
Baseline 1972



Baseline 1981



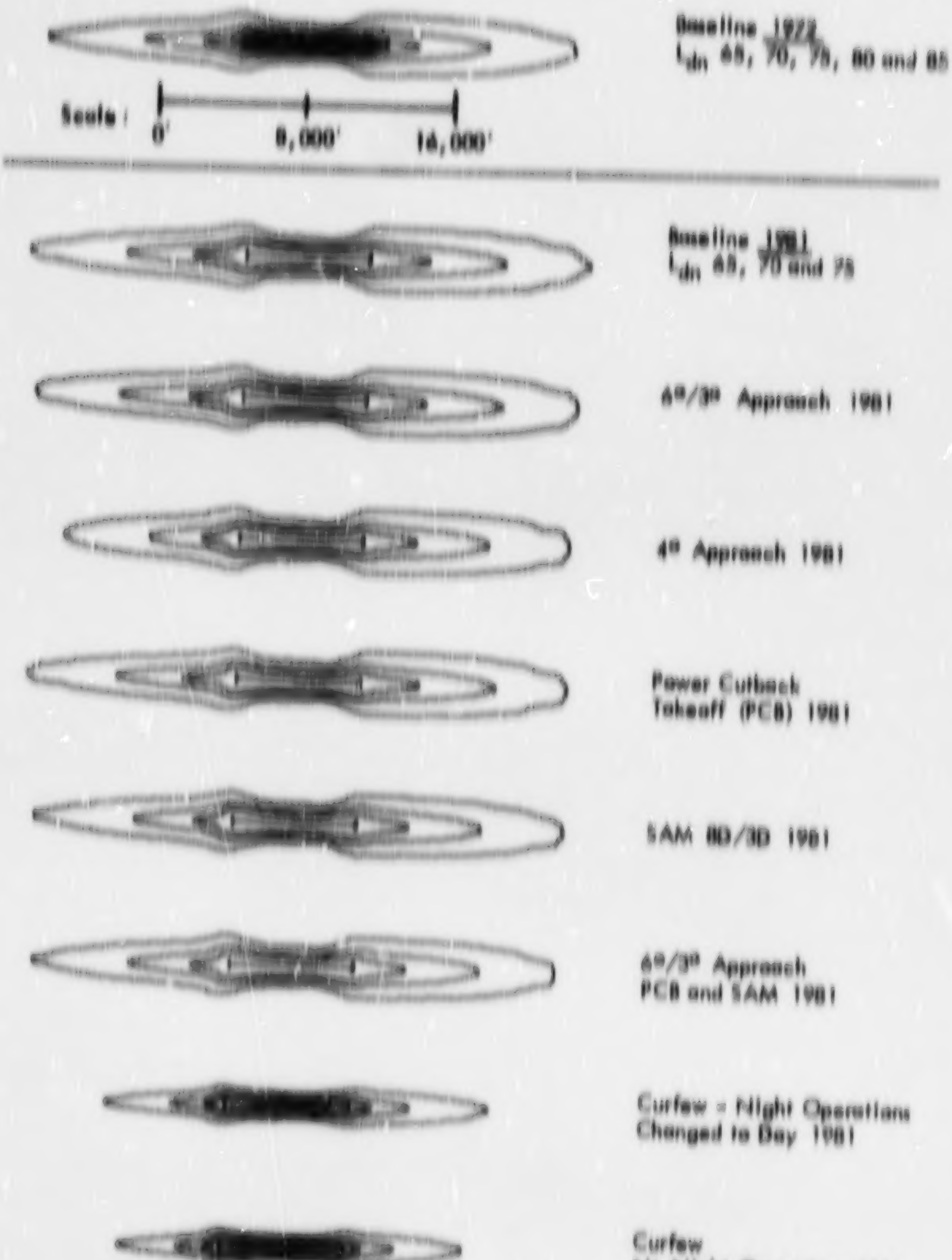
Power Cutback Takeoff (PCB) 1981



6°/3° Approach, PCB and SAM 1981

Scale: 0 8,000' 16,000'

Figure D-2. AVport III Abatement Alternatives – L_{dn} 65, 70, 75, 80 and 85 Contours



Baseline 1972
L_{dn} 65, 70, 75, 80 and 85

Baseline 1981
L_{dn} 65, 70 and 75

6°/3° Approach 1981

4° Approach 1981

Power Cutback
Takeoff (PCB) 1981

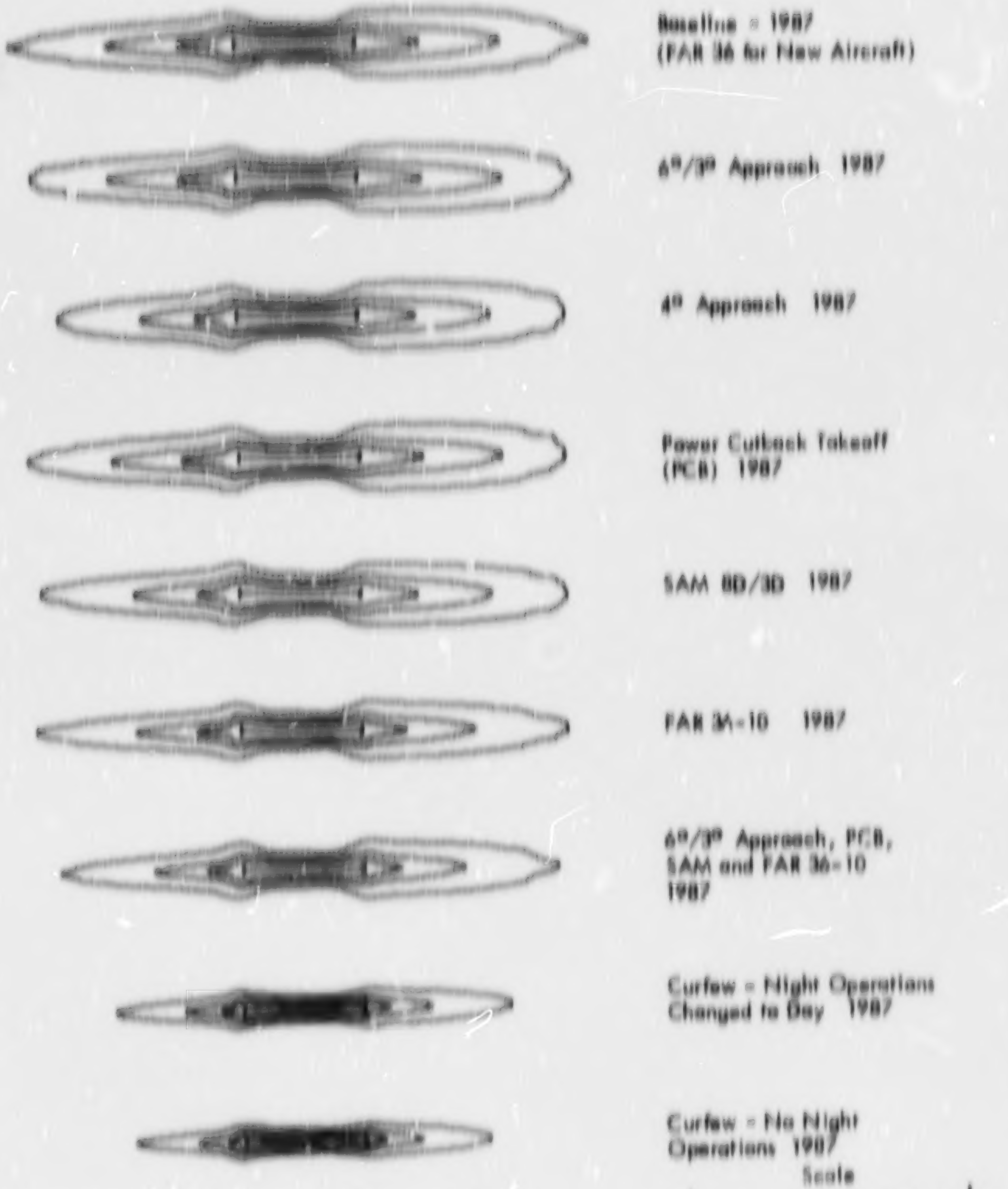
SAM 8D/3D 1981

6°/3° Approach
PCB and SAM 1981

Curfew - Night Operations
Changed to Day 1981

Curfew
No Night Operations 1981

Figure D-3. AVport II Abatement Alternatives, 1972 and 1981, L_{dn} 65, 70, and 75



Baseline - 1987
(FAR 36 for New Aircraft)

6°/3° Approach 1987

4° Approach 1987

Power Cutback Takeoff
(PCB) 1987

SAM 8D/3D 1987

FAR 36-10 1987

6°/3° Approach, PCB,
SAM and FAR 36-10
1987

Curfew - Night Operations
Changed to Day 1987

Curfew - No Night
Operations 1987

Figure D-4. AVport II Abatement Alternatives 1987
L_{dn} 65, 70, and 75

APPENDIX E

L_{dn} CONTOUR AREA AND POPULATION FOR AVPORTS AND AVTOWNS FOR EACH NOISE ABATEMENT ALTERNATIVE

Table E-1 provides the impact areas in square miles for each AVport and abatement alternative.

Table E-2 gives these values for all airports in each AVport category.

Table E-3 presents the total population for each of the abatement alternatives and for each AVtown category.

Table E-1
Area Within L_{dn} Contours for Each AVport
a) AVport I - Area in Square Miles

Year	Alternative	Contour Level (L_{dn}) 65	70	75	80	85
1972	Base	51.25	19.3	7.63	3.26	1.38
1981	Base	32.78	12.89	5.11	2.13	0.85
1981	Power Cutback	34.99	10.62	4.55	2.07	0.85
1981	4° Approach	31.87	11.50	4.68	2.01	0.80
1981	SAM 8D/3D	26.67	10.65	4.32	1.83	0.72
1981	6°/3° Approach	29.75	11.64	4.86	2.14	0.85
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	18.88	7.08	3.94	1.82	0.72
1981	Curfew - Night Flights Rescheduled to Day	17.97	7.00	2.90	1.18	0.48
1981	Curfew - Night Flights Eliminated	16.15	6.32	2.63	1.07	0.44
1987	Base	33.67	13.23	5.24	2.18	0.87
1987	Power Cutback	35.91	10.80	4.64	2.11	0.87
1987	4° Approach	32.78	11.93	4.80	2.07	0.83
1987	SAM 8D/3D	27.68	11.03	4.46	1.89	0.75
1987	6°/3° Approach	30.60	11.95	4.97	2.18	0.87
1987	6°/3° Approach, Power Cutback, SAM 8D/3D FAR 36-10 (Since 1981)	18.70	6.98	3.91	1.81	0.72
1987	Curfew - Night Flights Rescheduled to Day	19.14	7.49	3.08	1.26	0.51
1987	Curfew - Night Flights Eliminated	17.40	6.81	2.82	1.15	0.47
1987	FAR 36-10 (Since 1981)	32.34	12.40	5.01	1.99	0.83

Table E-1 (Continued)

b) AVport II - Area in Square Miles

Year	Alternative	Contour Level (L_{dn})				
		65	70	75	80	85
1972	Base	2.80	0.91	0.35	0.15	0.07
1981	Base	2.84	1.05	0.40	0.17	0.07
1981	Power Cutback	2.77	1.05	0.40	0.17	0.07
1981	4° Approach	2.63	0.97	0.38	0.17	0.07
1981	SAM 8D/3D	2.57	0.99	0.38	0.16	0.07
1981	6°/3° Approach	2.83	1.06	0.40	0.17	0.07
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	2.52	0.99	0.39	0.16	0.07
1981	Curfew - Night Flights Rescheduled to Day	1.09	0.41	0.17	0.07	0.03
1981	Curfew - Night Flights Eliminated	0.87	0.34	0.14	0.06	0.03
1987	Base	3.10	1.16	0.43	0.18	0.08
1987	Power Cutback	3.00	1.16	0.43	0.18	0.08
1987	4° Approach	2.87	1.07	0.41	0.17	0.08
1987	SAM 8D/3D	2.78	1.08	0.42	0.17	0.08
1987	6°/3° Approach	3.06	1.17	0.43	0.18	0.08
1987	6°/3° Approach, Power Cutback, SAM 8D/3D ' FAR 36-10 (Since 1981)	2.20	0.76	0.30	0.12	0.05
1987	Curfew - Night Flights Rescheduled to Day	1.21	0.45	0.19	0.08	0.04
1987	Curfew - Night Flights Eliminated	0.96	0.37	0.15	0.07	0.03
1987	FAR 36-10 (Since 1981)	2.41	0.85	0.33	0.14	0.06

Table E-1 (Continued)

c) AVport III - Area in Square Miles

Year	Alternative	Contour Level (L_{dn}) 65	70	75	80	85
1972	Base	5,23	2,02	0,75	0,32	0,13
1981	Base	5,83	2,16	0,79	0,33	0,14
1981	Power Cutback	5,60	2,14	0,79	0,32	0,14
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	4,39	1,97	0,77	0,33	0,14

Table E-2

Area Within L_{dn} Contours for All AVport Airports

a) AVport I – Area in Square Miles

Year	Alternative	Contour Level (L_{dn}) 65	70	75	80	85
1972	Base	2096.0	789.4	312.1	133.0	56.4
1981	Base	1353.8	532.4	211.0	88.0	35.1
1981	Power Cutback	1445.1	438.6	187.9	85.5	33.1
1981	4° Approach	1316.2	475.0	193.3	83.0	33.0
1981	SAM 8D/3D	1101.5	439.8	178.4	75.6	29.7
1981	6°/3° Approach	1228.7	480.7	200.7	88.4	35.1
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	779.7	392.4	162.7	75.2	29.7
1981	Curfew – Night Flights Rescheduled to Day	742.2	289.1	119.8	48.7	19.8
1981	Curfew – Night Flights Eliminated	667.0	261.0	108.6	44.2	18.2
1987	Base	1353.5	531.8	210.6	87.6	35.0
1987	Power Cutback	1443.6	434.2	186.5	84.8	35.0
1987	4° Approach	1317.8	479.6	193.0	83.2	33.4
1987	SAM 8D/3D	1112.7	443.4	179.3	76.0	30.2
1987	6°/3° Approach	1230.1	480.4	199.8	87.6	35.0
1987	6°/3° Approach, Power Cutback, SAM 8D/3D FAR 36-10 (Since 1981)	751.7	380.6	157.2	72.8	28.9
1987	Curfew – Night Flights Rescheduled to Day	769.4	301.1	123.8	50.7	20.5
1987	Curfew – Night Flights Eliminated	699.5	273.8	115.4	46.2	18.9
1987	FAR 36-10 (Since 1981)	1300.1	498.5	201.4	80.0	33.4

Table E-2 (Continued)

b) AVport II - Area in Square Miles

Year	Alternative	Contour Level (L_{dn})				
		65	70	75	80	85
1972	Base	368.5	134.1	51.6	22.1	10.3
1981	Base	405.0	149.7	57.0	24.2	10.0
1981	Power Cutback	395.0	149.7	57.0	24.2	10.0
1981	4° Approach	375.0	138.3	54.2	24.2	10.0
1981	SAM 8D/3D	366.5	141.2	54.2	22.8	10.0
1981	6°/3° Approach	403.6	151.2	57.0	24.2	10.0
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	359.4	141.2	55.6	22.8	10.0
1981	Curfew - Night Flights Rescheduled to Day	155.4	59.5	24.2	10.0	4.3
1981	Curfew - Night Flights Eliminated	124.1	48.5	20.0	8.5	4.3
1987	Base	396.8	148.5	55.0	23.0	10.2
1987	Power Cutback	384.0	148.5	55.0	23.0	10.2
1987	4° Approach	367.4	137.0	52.5	21.8	10.3
1987	SAM 8D/3D	355.8	138.2	53.8	21.8	10.2
1987	6°/3° Approach	391.7	149.8	55.0	23.0	10.2
1987	6°/3° Approach, Power Cutback, SAM 8D/3D FAR 36-10 (Since 1981)	281.6	97.3	38.4	15.4	6.4
1987	Curfew - Night Flights Rescheduled to Day	154.9	57.6	24.3	10.2	5.1
1987	Curfew - Night Flights Eliminated	122.9	47.4	19.2	9.0	3.8
1987	FAR 36-10 (Since 1981)	308.5	108.8	42.2	17.9	7.7

Table E-2 (Continued)

c) AVport III - Area in Square Miles

Year	Alternative	Contour Level (L_{dn})				
		65	70	75	80	85
1972	Base	276,1	106,7	37,6	16,9	6,9
1981	Base	287,4	106,5	38,9	15,8	6,9
1981	Power Cutback	276,1	105,5	38,9	15,8	6,9
1981	* 4° Approach	272,7	96,7	36,3	15,4	6,7
1981	* SAM 8D/3D	247,0	94,2	34,9	14,3	6,4
1981	* 6°/3° Approach	273,7	101,9	37,9	15,8	6,9
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	216,4	97,1	38,0	16,3	6,9
1981	* Curfew - Night Flights Rescheduled to Day	133,9	49,7	19,3	7,7	3,4
1981	* Curfew - Night Flights Eliminated	114,8	43,3	16,8	6,8	3,3
1987	* Base	284,5	106,0	38,2	15,4	7,0
1987	* Power Cutback	289,4	96,3	36,0	15,2	7,0
1987	* 4° Approach	270,2	96,7	35,7	14,6	6,8
1987	* SAM 8D/3D	244,4	93,5	34,9	14,0	6,5
1987	* 6°/3° Approach	269,6	101,3	37,2	15,4	7,0
1987	* 6°/3° Approach, Power Cutback, SAM 8D/3D FAR 36-10 (Since 1981)	179,6	62,7	27,6	11,6	5,0
1987	* Curfew - Night Flights Rescheduled to Day	136,5	50,6	19,7	7,9	3,8
1987	* Curfew - Night Flights Eliminated	117,8	44,3	17,0	7,1	3,2
1987	* FAR 36-10 (Since 1981)	247,5	88,6	33,0	13,1	5,9

Table E-3

Population Within L_{dn} Contours for All AViown Airports

a) AViown I - Population (000)

Year	Alternative	Contour Level (L_{dn})				
		65	70	75	80	85
1977	Base	6635,4	1968,7	606,1	138,7	13,0
1981	Base	4107,6	1347,8	359,6	57,3	5,0
1981	Power Cutback	4454,1	1055,6	293,6	43,2	3,0
1981	4° Approach	3967,9	1168,7	308,7	49,3	2,4
1981	SAM 8D/3D	3200,0	1059,4	267,3	38,3	1,5
1981	6°/3° Approach	3648,8	1186,7	329,9	58,0	3,0
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	2129,5	603,1	226,0	37,7	1,5
1981	Curfew - Night Flights Rescheduled to Day	2009,1	593,0	119,7	10,0	0,2
1981	Curfew - Night Flights Eliminated	1770,5	507,7	95,9	7,1	0,2
1987	Base	4507,8	1477,7	398,3	64,6	3,5
1987	Power Cutback	4885,2	1145,2	322,8	59,4	3,5
1987	4° Approach	4361,0	1300,0	342,7	56,5	2,9
1987	SAM 8D/3D	3551,6	1176,6	300,8	44,4	1,9
1987	6°/3° Approach	4008,6	1302,3	364,0	64,6	3,5
1987	6°/3° Approach, Power Cutback, SAM 8D/3D FAR 36-10 (Since 1981)	2235,5	629,9	235,3	39,4	1,6
1987	Curfew - Night Flights Rescheduled to Day	2397,5	695,4	144,9	13,2	0,3
1987	Curfew - Night Flights Eliminated	2053,4	604,2	119,4	9,7	0,1
1987	FAR 36-10 (Since 1981)	4289,0	1363,9	369,1	51,0	2,9

Table E-3 (Continued)

(b) AVtown II - Population (000)

Year	Alternative	Contour Level (L_{dn})				
		65	70	75	80	85
1972	Base	179,7	30,4	2,5	0,1	0,003
1981	Base	228,5	43,6	4,0	0,2	0,003
1981	Power Cutback	220,9	43,6	4,0	0,2	0,003
1981	4° Approach	205,5	37,0	3,4	0,2	0,003
1981	SAM 8D/3D	199,0	38,6	3,4	0,2	0,003
1981	6°/3° Approach	227,4	44,4	4,0	0,2	0,003
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	193,5	38,6	3,7	0,2	0,003
1981	Curfew - Night Flights Rescheduled to Day	47,0	4,3	0,2	0,003	0,000
1981	Curfew - Night Flights Eliminated	29,4	2,4	0,09	0,001	0,000
1987	Base	251,6	52,0	4,9	0,3	0,006
1987	Power Cutback	240,9	52,0	4,9	0,3	0,006
1987	4° Approach	227,0	44,3	4,2	0,2	0,006
1987	SAM 8D/3D	217,3	45,1	4,5	0,2	0,006
1987	6°/3° Approach	247,3	52,6	4,9	0,3	0,006
1987	6°/3° Approach, Power Cutback, SAM 8D/3D FAR 36-10 (Since 1981)	155,3	21,2	1,6	0,04	0,000
1987	Curfew - Night Flights Rescheduled to Day	56,4	5,5	0,3	0,006	0,000
1987	Curfew - Night Flights Eliminated	35,5	3,1	0,1	0,003	0,000
1987	FAR 36-10 (Since 1981)	177,7	27,3	2,2	0,09	0,001

Table E-3 (Continued)

c) AVtown III - Population (000)

Year	Alternative	Contour Level (L_{dn})				
		65	70	75	80	85
1972	Base	274,4	71,1	7,7	0,4	0,005
1981	Base	318,3	82,0	9,0	0,4	0,008
1981	Power Cutback	304,4	80,7	9,1	0,4	0,008
1981	4° Approach	300,1	69,2	7,6	0,4	0,008
1981	SAM 8D/3D	268,1	66,1	6,7	0,3	0,008
1981	6°/3° Approach	301,4	76,2	8,5	0,4	0,008
1981	6°/3° Approach, Power Cutback, SAM 8D/3D	228,8	69,8	8,5	0,5	0,008
1981	Curfew - Night Flights Rescheduled to Day	118,8	17,2	0,9	0,02	0,00
1981	Curfew - Night Flights Eliminated	93,0	12,1	0,5	0,008	0,00
1987	Base	345,5	92,9	10,6	0,5	0,01
1987	Power Cutback	352,2	79,0	8,9	0,5	0,01
1987	4° Approach	326,0	79,7	8,6	0,4	0,01
1987	SAM 8D/3D	291,8	75,1	8,3	0,3	0,008
1987	6°/3° Approach	326,0	86,3	9,9	0,5	0,01
1987	6°/3° Approach, Power Cutback, SAM 8D/3D FAR 36-10 (Since 1981)	201,1	34,6	4.1	0,2	0,002
1987	Curfew - Night Flights Rescheduled to Day	137,6	21,5	1,4	0,02	0,000
1987	Curfew - Night Flights Eliminated	110,4	15,5	0,8	0,01	0,000
1987	FAR 36-10 (Since 1981)	296,2	68,0	7,1	0,3	0,005

APPENDIX F

ESTIMATING PROCEDURES FOR ADDITIONAL ALTERNATIVES

The following outlines the methods used to estimate results for the noise reduction alternatives which were not evaluated by AVport noise contours. These are the REFAN options - and most of the alternatives for AVport III.

ESTIMATED REFAN OPTION

The results from the Wyle/DOT 23 Airport Study[1] were used to estimate the national impact for the case involving a REFAN option. This procedure was employed in lieu of computing L_{dn} noise contours for this case. In the reference report, the REFAN option is treated as a composite alternative involving:

- 6°/3° glide slope on approach
- SAM JT3D engines (B-707, DC-8)
- REFAN JT8D engines (B-727, B-737, DC-9)

For this report, it was assumed that the relative decrease in total contour area for the above option when compared to the 6°/3° + SAM 3D/8D option will be the same as the relative decrease in contour area for each of the AVport models in this study between a REFAN 8D/SAM3D option and the SAM 3D/8D option. That is, it is assumed that

$$\text{National Contour Area (REFAN8D/SAM3D)} = \text{National Contour Area(SAM 3D/8D)}$$

$$\times \left[\frac{\text{23 Airport Contour Area(REFAN 8D/SAM 3D + 6°/3°)}}{\text{23 Airport Contour Area (SAM 3D/8D + 6°/3°)}}\right]$$

The ratios of NEF contour areas from the 23 airports (given in Table F-1) are assumed equal to area ratios for comparable L_{dn} values (i.e., NEF 30 = L_{dn} 65, etc.).

From these ratios, and the contour areas for the SAM 3D/8D case, (Table E-2, Appendix E) the estimated contour areas for the REFAN option given in Table F-2 are

Table F-1

Absolute and Relative Contour Areas for REFAN Option from 23 Airport Study[1]

Year	Alternatives	NEF, dB 30	 35	 40	 45	 50
		Absolute Contour Area, Square Miles				
1978	SAM 3D/8D + 6°/3°	640	(265)	110	45	
1981	SAM 3D/8D + 6°/3°	(641)	(262)	(113)	(48)	
1987	SAM 3D/8D + 6°/3°	642	260	115	(51)	
1981	REFAN 8D SAM 3D + 6°/3°	305	(142)	66	25	
1987	REFAN 8D SAM 3D + 6°/3°	337	154	71	(33)	
		Relative Contour Areas				
1981	[2]REFAN / SAM	0.476	0.542	0.584	0.521	(0.52)
1987	[2]REFAN / SAM	0.525	0.592	0.617	0.647	(0.65)

[1] Designates estimated value.

[2] Ratio of Areas

Table F-2

AVport and National Contour Areas for REFAN Option
(Square Miles)

Year	Alternatives	L_{dn}, dB				
		65	70	75	80	85
1981						
AVport I	REFAN 8D SAM 3D	524	238.4	104.2	39.4	15.4
AVport II	REFAN 8D SAM 3D	174.5	76.5	31.7	11.9	5.2
AVport III	REFAN 8D SAM 3D	117.6	51.1	20.4	7.5	3.3
National Composite	REFAN 8D SAM 3D	816.1	365.8	156.3	58.8	23.9
1987						
AVport I	REFAN 8D SAM 3D	584.2	262.5	110.6	49.2	19.6
AVport II	REFAN 8D SAM 3D	186.8	81.8	33.2	14.1	6.6
AVport III	REFAN 8D SAM 3D	128.1	55.4	21.5	9.1	4.2
National Composite	REFAN 8D SAM 3D	899.1	399.7	165.3	72.4	30.4

obtained. For the 1981 period, the contour areas were interpolated from results for 1978 and 1987 in the 23 airport report.

The estimates of impacted population and noise units, in Tables F-3 and F-4, were obtained with the preceeding data by the methods outlined in Section 2.

ADDITIONAL CASES FOR AVPORT III

Due to the limited number of alternatives actually computed for AVport III, an interpolation scheme was required to estimate contour areas for the other alternatives for the midrange airport. Based on the consistent relationships between operations and contour areas, it was found that satisfactory estimates of contour areas could be obtained by the average of the change in area, relative to a reference baseline case, observed for AVports I and II. This can be expressed as

$$\frac{A_{III(x)}}{A_{III(Ref)}} = \frac{1}{2}\left[\frac{A_{I(x)}}{A_{I(Ref)}} + \frac{A_{II(x)}}{A_{II(Ref)}}\right]$$

where

$A_{(x)}$ = Contour area for any (x) alternative

and

$A_{(Ref)}$ = Contour area for the reference (baseline) alternative

Following this procedure, the additional cases for AVport III could be estimated to determine total impact areas, population and noise units.

Table F-3

National Population (000) for REFAN Option

Year	Alternatives	L_{dn}, dB				
		65	70	75	80	85
1981						
AVtown I	REFAN 8D SAM 3D	1322,0	439,6	86,8	4,6	0,06
AVtown II	REFAN 8D SAM 3D	58,5	9,1	0,6	0,007	-
AVtown III	REFAN 8D SAM 3D	96,3	18,4	1,1	0,013	-
National Composite	REFAN 8D SAM 3D	1476,8	467,1	88,5	4,62	0,06
1987						
AVtown I	REFAN 8D SAM 3D	1656,0	566,9	112,8	11,9	0,27
AVtown II	REFAN 8D SAM 3D	79,6	14,0	1,0	0,03	-
AVtown III	REFAN 8D SAM 3D	125,3	26,4	1,8	0,05	-
National Composite	REFAN 8D SAM 3D	1860,9	607,3	115,6	11,98	0,27

Table F-4

Estimated Noise Units for REFAN Option

Year	L_{dn} band, dB					NU Sum (000)
	65-70	70-75	75-80	80-85	> 85	
1981						
Area, mi^2	480,3	209,5	97,5	34,9	23,9	
Pop. (000)	1009,7	378,6	83,9	4,56	0,06	
Noise Units	651,3	345,3	97,3	6,4	0,10	1100.4
1987						
Area, mi^2	499,4	234,4	92,9	42,0	30,4	
Pop. (000)	1253,6	491,7	103,6	11,7	0,27	
Noise Units	779,6	443,3	120,1	16,5	0,45	1360.0

APPENDIX G
CALCULATION OF ECONOMIC INDICATORS

The basis for all calculations of the economic indicators was the 1970 Censuses of Population and Housing First Count Summary Tape. This tape contains summary economic data for each of the population centroids within a large radius of the airport locations for three major U.S. cities, Atlanta, Minneapolis-St. Paul, and Seattle.

Key economic data for each of the population centroids falling within any one of 2000 by 2000 feet grid squares constructed around these airports was accumulated if the grid square met the following criteria:

1. It had nonzero population.
2. The rounded (nearest 1 dB) aircraft L_{dn} value was 65 dB or greater.

Additionally, all the required economic data was separated into one or more of the L_{dn} noise level bands. In addition to the economic data, the population, and number of population centroids were recorded, and the Noise Units calculated according to the procedures outlined in Section 2.6.1 of the main body of this report and based on a population density computed from the total population in each grid square.

After the accumulation process, three additional economic parameters were calculated from the accumulated values for each band.

1. Aggregate Owner Value =

$$\left(\frac{\text{Total Owner}}{\text{Occupied Units}} + \frac{\text{Total Units}}{\text{Vacant for Sale}}\right) + \left(\frac{\text{Other Vacant}}{\text{Units}}\right) \times \frac{\left(\frac{\text{Dollar Value}}{\text{Owner Occupied}} + \frac{\text{Dollar Value}}{\text{Vacant for Sale}}\right)}{\left(\frac{\text{Total Owner Occupied}}{\text{with Tabulated Value}} + \frac{\text{Total Units Vacant for Sale}}{\text{with Tabulated Value}}\right)} \times [illegible]$$

2. Aggregate Monthly Contract Rent =

$$\left(\frac{\text{Total Renter}}{\text{Occupied Units}} + \frac{\text{Total Vacant}}{\text{For Rent}}\right) \times \frac{\left(\frac{\text{Monthly Rent}}{\text{Occupied Units}} + \frac{\text{Monthly Rent}}{\text{Vacant Units}}\right)}{\left(\frac{\text{Occupied Units for}}{\text{Which Rent is Tabulated}} + \frac{\text{Vacant Units for}}{\text{Which Rent is Tabulated}}\right)}$$

3. Total Aggregate Value =

Aggregate Owner Value + (Aggregate Contract Rent × $100)

Table G-1 identifies the first count census data variables available for the economic analysis of "receiver" noise abatement alternatives.

Table G-2 reflects the first count census data averages for Minneapolis, Atlanta, and Seattle for each L_{dn} band.

Table G-1

First Count Census Data Variables

Code		Code	
[illegible]	1. Count of all Persons	[illegible]	31. Number of Units No Direct Access Complete Kitchen
[illegible]	2. Count of all Housing Units	[illegible]	32. Number of Units No Direct Access Incomplete Kitchen
[illegible]	3. Aggregate $ Value — Total Owner Occupied	[illegible]	33. Number Units Tabulated with Value [illegible]
[illegible]	4. Aggregate $ Value — Vacant For Sale	[illegible]	34. Number of Units Tabulated with Value [illegible]
[illegible]	5. Aggregate $ Monthly Rent — Total Renter Occupied	[illegible]	35. Number of Units Tabulated with Value [illegible]
[illegible]	6. Aggregate $ Monthly Rent — Vacant For Rent	[illegible]	36. Number of Units Tabulated with Value [illegible]
[illegible]	7. Aggregate $ Value Units with Plumbing Facilities — Total Owner Occupied	[illegible]	37. Number of Units Tabulated with Value [illegible]
[illegible]	8. Aggregate $ Value Units with Plumbing Facilities — Vacant For Sale	[illegible]	38. Number of Units Tabulated with Value [illegible]
[illegible]	9. Aggregate $ Monthly Contract Rent for Units with Plumbing — Total Renter Occupied	[illegible]	39. Number of Units Tabulated with Value [illegible]
[illegible]	10. Aggregate $ Monthly Contract Rent for Units with Plumbing — Vacant For Rent	[illegible]	40. Number of Units Tabulated with Value [illegible] and More
[illegible]	11. Total Owner Occupied Units	[illegible]	41. Total Owner Occupied for Value
[illegible]	12. Total Renter Occupied Units	[illegible]	42. Total Vacant For Sale
[illegible]	13. Total Units Vacant For Rent	[illegible]	43. Rent [illegible] for Rent
[illegible]	14. Total Units Vacant For Sale	[illegible]	44. Rent [illegible]
[illegible]	15. Other Vacant Year Round Units	[illegible]	45. Rent [illegible]
[illegible]	16. Number of Units in One Unit Structures	[illegible]	46. Rent [illegible]
[illegible]	17. Number of Units in Two or More Unit Structures	[illegible]	47. Rent [illegible]
[illegible]	18. Number of Mobile Homes and Trailers Occupied Only	[illegible]	48. Rent [illegible]
[illegible]	19. Number of Units with One Room	[illegible]	49. Rent [illegible]
[illegible]	20. Number of Units with Two Rooms	[illegible]	50. Rent [illegible]
[illegible]	21. Number of Units with Three Rooms	[illegible]	51. Rent [illegible] and More
[illegible]	22. Number of Units with Four Rooms	[illegible]	52. Without Payment of Cash Rent
[illegible]	23. Number of Units with Five Rooms	[illegible]	53. Total Renter Occupied for Rent
[illegible]	24. Number of Units with Six Rooms	[illegible]	54. Total Vacant for Rent
[illegible]	25. Number of Units with Seven Rooms	[illegible]	55. Total Units with Plumbing
[illegible]	26. Number of Units with Eight or more Rooms	[illegible]	56. Total Units with Plumbing Lacking One or More
[illegible]	27. Aggregate Number of Rooms	[illegible]	57. Number of Units with One Flushing Toilet
[illegible]	28. Total Units with Basement	[illegible]	58. Number of Units with Shared Flushing Toilet
[illegible]	29. Number of Units Direct Access Complete Kitchen	[illegible]	59. Number of Units with No Flushing Toilet
[illegible]	30. Number of Units Direct Access Incomplete Kitchen		

Table G-2

First Count Census Data – Averages for Three Airports (MSP, ATL, SEA)

Results for Aircraft L_{dn} Band ≥65							
Data Sup Code Ind	Value	Data Sup Code Ind	Value	Data Sup Code Ind	Value	Data Sup Code Ind	Value
001001		002001	22659	014001 *	1325683	014002 *	7081
015001 *	1232100	015003 *	140847	016001 *	1318175	016002 *	7069
017001 *	1090265	017003 *	132742	026001 *	16143	026004 *	72815
026007 *	1211	026008 *	164	026009 *	283	027001 *	18007
027002 *	9026	027003 *	410	028001 *	1154	028002 *	1442
028003 *	3774	028004 *	5873	028005 *	6782	028006 *	5097
028007 *	2537	028008 *	1968	028009 *	138522	032001 *	17415
033001 *	27784	033002 *	322	033003 *	13	033004 *	8
035001 *	84	035002 *	528	035003 *	2171	035004 *	4366
035005 *	3957	035006 *	2525	035007 *	726	035008 *	275
035009 *	15024	035011 *	75	036001 *	458	036002 *	1024
036003 *	1249	036004 *	1414	036005 *	1371	036006 *	2434
036007 *	1984	036008 *	544	036009 *	30	036010 *	286
036011 *	19428	036013 *	1150	041001 *	27520	041002	1110
045001 *	27725	045002 *	736	045003 *	166		

Total Population	91074
Noise Unit	40611.94
Noise Unit per Person	0.45
Number of Cells	124
Number of People per Cell	734.47

Aggregate Owner Value	$265.59 m
Aggregate Contract Unit x $100	$142.80
Total Aggregate Value	$508.38 m

Table G-2 (Continued)

Results for Aircraft L_{dn} Band ≥ 75							
Data Sup Code Ind	Value	Data Sup Code Ind	Value	Data Sup Code Ind	Value	Data Sup Code Ind	Value
001001		002001	4122	014001 *	155872	014002 *	413
015001 *	230360	015002 *	12615	016001 *	154285	016002 *	413
017001 *	197137	017002 *	12513	026001 *	2153	026004 *	1800
026007 *	110	026008 *	18	026009 *	37	027001 *	2586
027002 *	1450	027003 *	82	029001 *	29	029002 *	96
029002 *	522	029004 *	1163	029005 *	1115	029006 *	699
029007 *	269	029008 *	186	029019 *	19850	032001 *	1025
033001 *	4043	033002 *	70	033003 *	2	033004 *	3
035001 *	26	035002 *	135	035003 *	472	035004 *	596
035005 *	450	035006 *	284	035007 *	63	035008 *	18
035009 *	1980	035011 *	7	036001 *	59	035012 *	29
036003 *	166	036004 *	347	036005 *	306	036006 *	466
036007 *	254	036008 *	115	036009 *	3	036101 *	32
036011 *	1740	036013 *	347	047001 *	3987	047002	131
045001 *	4031	045002 *	23	045003 *	54		

Total Population	16599
Noise Unit	12707.53
Noise Unit per Person	.77
Number of Cells	42
Number of People per Cell	395.21

Aggregate Owner Value	$43.10 m
Aggregate Contour Unit x 3700	$22.10 m
Total Aggregate Value	$65.20 m

Table G-2 (Continued)

Results for Aircraft L_{dn} Band=85							
Data Sup Code Ind	Value	Data Sup Code Ind	Value	Data Sup Code Ind	Value	Data Sup Code Ind	Value
001001		002001	256	014001 *	4592	014003 *	0
015001 *	15532	015002 *	1040	016001 *	4290	016003 *	0
017001 *	15090	017002 *	1280	026001 *	80	026006 *	159
026007 *	11	026008 *	1	026009 *	5	027001 *	130
027002 *	126	027003 *	0	028001 *	2	029002 *	12
029003 *	53	029004 *	72	029005 *	56	029006 *	38
029007 *	14	029008 *	7	029009 *	1153	032001 *	64
033001 *	248	033002 *	6	033003 *	0	033004 *	2
035001 *	2	035002 *	9	035003 *	26	035004 *	20
035005 *	5	035006 *	4	035007 *	2	035008 *	1
035009 *	69	035011 *	0	036001 *	12	036002 *	19
036003 *	27	036004 *	23	036005 *	20	036006 *	35
036007 *	35	036008 *	0	036009 *	1	036101 *	4
036011 *	154	036013 *	10	047001 *	238	047002	18
045001 *	249	045002 *	4	045003 *	2		

Total Population	677	Aggregate Owner Value	$1.417 M
Noise Unit	821.11	Aggregate Contract Unit + $100	$11.722 M
Noise Unit per Person	1.21	Total Aggregate Value	$2.139 M
Number of Cells	2		
Number of People per Cell	338.50		

Table G-2 (Continued)

Results for Aircraft L_{dn} Band 65–69

Dsta Sup Code Ind	Value	Dsta Sup Code Ind	Value	Dsta Sup Code Ind	Value	Dsta Sup Code Ind	Value
001001		002001	14674	014001 *	617151	014003 *	3678
015001 *	645175	015003 *	86813	016001 *	614255	016003 *	3666
017001 *	670273	017003 *	7890	026001 *	7469	026004 *	6067
026007 *	8111	026008 *	81	026009 *	168	027001 *	8534
027002 *	5857	027003 *	206	028001 *	1064	028002 *	1171
028003 *	2146	028004 *	2621	028005 *	3442	028006 *	2353
028007 *	1174	028008 *	1010	028009 *	66913	032001 *	9607
033001 *	13939	033002 *	657	033003 *	7	033004 *	4
035001 *	28	035002 *	213	035003 *	959	035004 *	2010
035005 *	1873	035006 *	1429	035007 *	333	035008 *	93
035009 *	6938	035011 *	37	036001 *	351	036002 *	835
036003 *	864	036004 *	793	036005 *	633	036006 *	1172
036007 *	962	036008 *	238	036009 *	28	036101 *	148
036011 *	5874	036013 *	785	041001 *	13751	041002	845
045001 *	13855	045002 *	699	045003 *	42		

Total Population	40115	Aggregate Owner Value	$171.58M
Noise Unit	11725.21	Aggregate Contract Unit x $100	$ 75.76M
Noise Unit per Person	0.29	Total Aggregate Value	$247.33M
Number of Cells	47		
Number of People per Cell	853.51		

Table G-2 (Continued)

Results for Aircraft L_{dn} Band 70 – 74							
Dem Sup Code Ind	Value	Dem Sup Code Ind	Value	Dem Sup Code Ind	Value	Dem Sup Code Ind	Value
001001		002001	9902	014001 *	552717	014003 *	2990
015001 *	386566	015003 *	23787	016001 *	549535	016003 *	2990
017001 *	382962	017003 *	41320	026001 *	5521	026006 *	2948
026007 *	290	026008 *	65	026009 *	88	027001 *	7787
027002 *	2520	027003 *	206	028001 *	61	028002 *	175
028003 *	1066	028004 *	2091	028005 *	2614	028006 *	2046
028007 *	1088	028008 *	772	028009 *	51758	[illegible] *	5980
033001 *	9813	033002 *	95	033003 *	4	033004 *	0
035001 *	29	035002 *	180	035003 *	799	035004 *	1761
035005 *	1637	035006 *	1264	035007 *	321	035008 *	109
035009 *	6786	035011 *	33	036001 *	48	036002 *	99
036003 *	217	036004 *	275	036005 *	432	036006 *	777
036007 *	688	036008 *	276	036009 *	3	036101 *	102
036011 *	2815	036013 *	265	041001 *	9779	041002	134
045001 *	9839	045002 *	4	045003 *	60		

Total Population	34360	Aggregate Owner Value	$150.91 M
Noise Unit	16179.20	Aggregate Contract Unit x $100	$ 44.93 M
Noise Unit per Person	.47	Total Aggregate Value	$195.84 M
Number of Cells	35		
Number of People per Cell	462.26		

Table G-2 (Continued)

Results for Aircraft L_{dn} Band 75 – 79							
Dem Sup Code Ind	Value	Dem Sup Code Ind	Value	Dem Sup Code Ind	Value	Dem Sup Code Ind	Value
001001		002001	2644	014001 *	119105	014002 *	315
015001 *	122117	015002 *	9318	016001 *	118462	016002 *	315
017001 *	121019	017002 *	9295	026001 *	1492	026004 *	1044
026007 *	77	026008 *	11	026009 *	16	027001 *	1754
027002 *	881	027003 *	55	028001 *	22	028002 *	54
028003 *	358	028004 *	594	028005 *	729	028006 *	455
028007 *	203	028008 *	147	028009 *	12967	032001 *	1459
033001 *	2623	033002 *	15	033003 *	2	033004 *	0
035001 *	10	035002 *	55	035003 *	195	035004 *	412
035005 *	389	035006 *	261	035007 *	54	035008 *	11
035009 *	1390	035011 *	4	036001 *	13	036002 *	30
036003 *	78	036004 *	202	036005 *	182	036006 *	322
036007 *	171	036008 *	11	036009 *	2	036101 *	19
036011 *	1011	035013 *	72	047001 *	2605	047002	36
045001 *	2619	045002 *	11	045003 *	11		

Total Population	11326
Noise Unit	7480.95
Noise Unit per Person	0.66
Number of Cells	35
Number of People per Cell	323.61

Aggregate Owner Value	322.45 K
Aggregate Contour Unit x [illegible]	[illegible] K
Total Aggregate Value	[illegible] M

Table G-2 (Continued)

Results for Aircraft L_{dn} Band 80 – 84							
Dem Sup Code Ind	Value	Dem Sup Code Ind	Value	Dem Sup Code Ind	Value	Dem Sup Code Ind	Value
001001		002001	1223	014001 *	32115	014002 *	98
015001 *	62712	015003 *	2257	016001 *	31452	016003 *	98
017001 *	61025	017003 *	2216	026001 *	581	026004 *	597
026007 *	22	026009 *	6	026010 *	15	027001 *	753
027002 *	443	027003 *	27	028001 *	4	028002 *	31
028003 *	151	028004 *	397	028005 *	348	028006 *	287
028007 *	52	028008 *	31	028009 *	5731	032001 *	301
033001 *	1172	033002 *	46	033003 *	0	033004 *	2
035001 *	15	035002 *	71	035003 *	189	035004 *	164
035005 *	36	035006 *	19	035007 *	7	035008 *	1
035009 *	521	035011 *	2	036001 *	34	036002 *	40
036003 *	64	036004 *	121	036005 *	105	036006 *	127
036007 *	67	036008 *	18	036009 *	0	036101 *	13
036011 *	575	036013 *	19	041001 *	1145	041002	77
045001 *	1162	045002 *	8	045003 *	52		

Total Population	4596	Aggregate Owner Value	$ 9.23 m
Noise Unit	4405.47	Aggregate Contract Unit x $100	$ 6.78 m
Noise Unit per Person	0.96	Total Aggregate Value	$16.01 m
Number of Cells	5		
Number of People per Cell	919.20		

APPENDIX H

ANALYSIS OF NOISE IMPACT FROM GENERAL AVIATION AIRCRAFT

H.1 INTRODUCTION

The prediction of the national noise impact from general aviation aircraft was accomplished through a modeling procedure. The first step in the analysis was an assessment and definition of the overall operations of general aviation aircraft and airports across the nation. General aviation airports were grouped into GA airport categories and a computer analysis made of the noise environment in each category.

The entire analysis was divided into the following steps:

1. Statistical assemblage of the number of annual operations at each airport for the present time period.*
2. Breakdown of the total number of airports which could handle jet aircraft into categories by runway length.
3. Breakdown of the general aviation jet, turboprop and piston aircraft fleet by capabilities to operate within certain runway length categories.
4. Combining the various airport categories in Step (2) and the aircraft categories in Step (3) into four categories, called GAVports, according to their ability to handle the various types of GA aircraft.
5. Evaluation of the number of operations per aircraft for each of the four GAVports.

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*The data used in the general aviation analysis was limited and had to be accumulated over the time period primarily between 1972 and 1974. For convenience and the need for simplification, this data was considered to represent the present time period.

6. Definition of noise and performance data for the general aviation fleet.

7. Computer analysis of noise for the present time period.

8. Estimate of the noise impact in the future.

H.2 PROFILE OF GA OPERATIONS PER AIRPORT

A listing of the total number of operations was provided by the FAA for 6610 airports with exclusively GA aircraft[1,2]* Airports with both air carrier and GA operations in this listing were not counted. From this FAA list, 147 airports were sampled for the distribution of number of airports by number of operations and this profile extrapolated to the nation.

Figure H-1 is the resulting histogram of the number of airports by average annual operations per airport. The three airports designated to have 400,000 to 600,000 annual operations are in a special category that represents three exceptionally large GA airports with average annual operations of 556,000.

H.3 AIRPORTS CAPA[illegible]F HANDLING JETS

The criteria set for each airport that specifies whether or not it is capable of handling jets was based on the availability of jet fuel at the particular site. Such data were available by categories of runway lengths for 48 states.[3] The remaining two states were taken into account by normalizing the GA airports by category type.

H.4 RUNWAY LENGTH REQUIREMENTS FOR JET, TURBOPROP AND PISTON AIRCRAFT

The propulsion system characteristics of jet, turboprop and piston aircraft were correlated to the airport runway length categories defined in Table H-1. The

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*See References at the end of this Appendix.

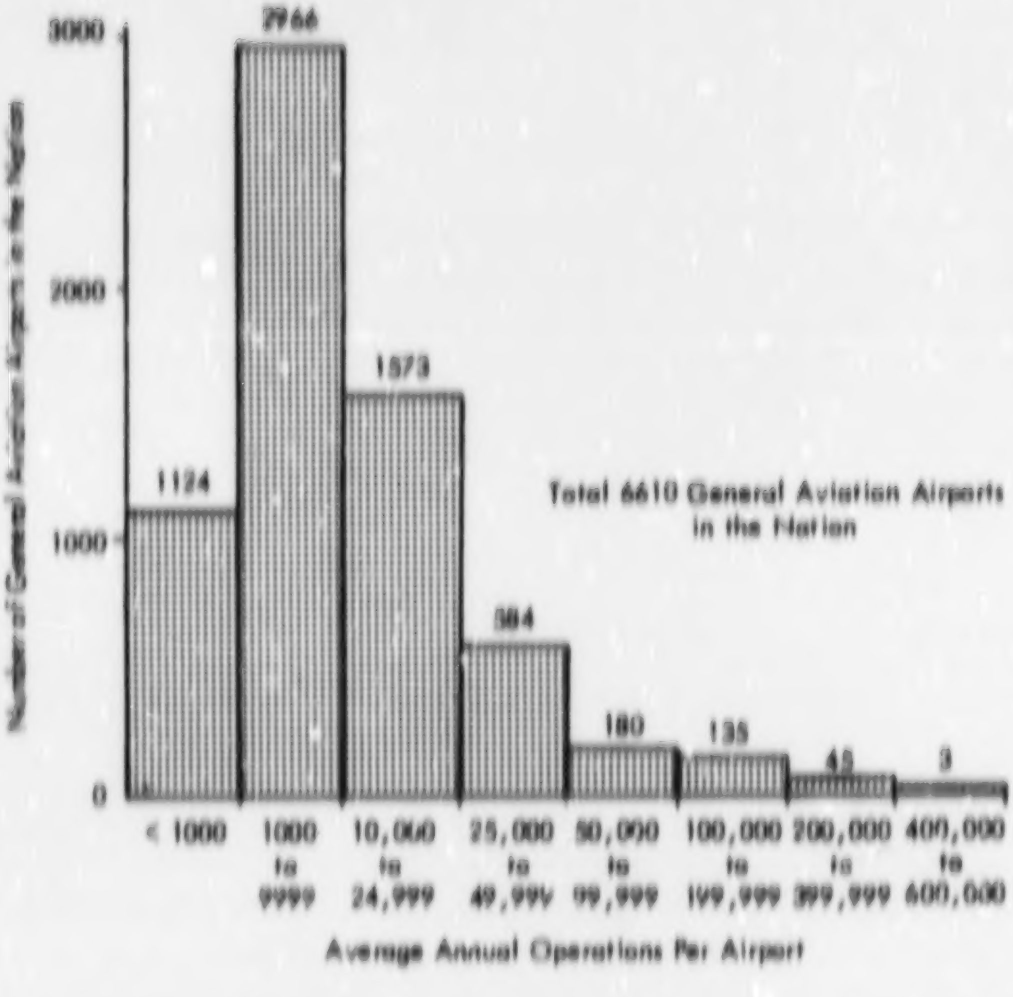

Figure H-1. Estimated Distribution of General Aviation Airports by Annual Operations Over the Nation[1,2]

Table H-1

Number of General Aviation Airports in the Nation With and Without Jet Fuel Facilities[1,2,3]

Airport Type	With Jet Fuel	Without Jet Fuel
Large Airports (runway length > 4750 feet)	178 Airports	1182 Airports
Medium Airports (3500 feet < runway length ≤ 4750 feet)	203 Airports	
Small Airports (runway length ≤ 3500 feet)	0 Airports (runway too short for jets)	5047 Airports
Total	6610 Airports	

appropriate parameter related to noise is the thrust for jets and horsepower for prop aircraft.

Trends of the performance data for jets indicate that jet aircraft rated at maximum thrust over 8000 pounds typically require runways greater than 4750 feet.[4] Prop aircraft, turboprop and piston engine powered, over 12,500 pounds maximum gross weight, generally require runways greater than 3500 feet.[4] For propeller aircraft, there is a close correlation between shaft horsepower and gross weight.[5] The relation indicates aircraft over 12,500 pounds gross weight need a minimum of 1450 horsepower. Thus, prop aircraft rated at 1450 horsepower or greater were assumed to utilize runways with minimum lengths of 3500 feet.

H.5 DEFINITION OF THE FOUR GAVPORT CATEGORIES

Four average general aviation airport (GAVport) categories were defined that would enable extrapolation to the nation of their acoustic environment. The bases for the particular breakdown of "average" airports indicated in this study was taken from Table H-1. These categories were defined by the following descriptions:

1. Large GAVport – with jets and props (runway length > 4750 feet).
2. Medium GAVport – with jets and props (3500 feet < runway length ≤ 4750 feet).
3. Large GAVport – without jets and with props (runway length > 3500 feet).
4. Small GAVport – without jets and with props (runway length ≤ 3500 feet).

Under each of these headings various aircraft types were assigned by jet and prop aircraft runway requirements according to thrust or shaft horsepower. As a result, a breakdown of GA aircraft type according to the four GAVports was the next step. This breakdown is summarized in Table H-2.

H.6 DEFINITION OF OPERATIONS PER AIRCRAFT TYPE

The number of operations per airport were given by the national distribution of airports in Figure H-1. Multiplying the midpoint of each distribution band with the total number of airports in each respective band gave a total of 115,220,500 GA operations per year for the nation. These 115,220,500 operations were distributed over the four GAVports in a top-down manner which supported a conservative noise estimate. The 178 GA airports in the "Large GAVport with jets" category were assumed to make up the first 178 airports with the most activity in the distribution in Figure H-1. The next 202 most active GA airports below the first 178 were designated to the Medium GAVport category. The Large GAVports without jets were assigned the 1182 airports with the highest number of operations per airport below the 178 and 202 airports already assigned. The remaining 5048 airports were assigned to the Small GAVport category. Figure H-2 illustrates the resulting assumed distribution of the nation's GA airports by the four GAVport categories.

Table H-2

General Aviation GAVport Categories by Assumed Distribution of Aircraft Type and Number of Airports in the Nation

GAVport Category	Aircraft Type						Number of Airports in the Nation
	Large Jets (≥[illegible]# Thrust)	Small Jets (<[illegible]# Thrust)	Large Turboprop (≥1450 hp)	Small Turboprop (<1450 hp)	Large Piston (≥1450 hp)	Small Piston (<1450 hp)	
Large GAVport with Jets	X	X	X	X	X	X	178
Medium GAVport		X	X	X	X	X	202
Large GAVport without Jets			X	X	X	X	1182
Small GAVport				X		X	5048
						Total	6610

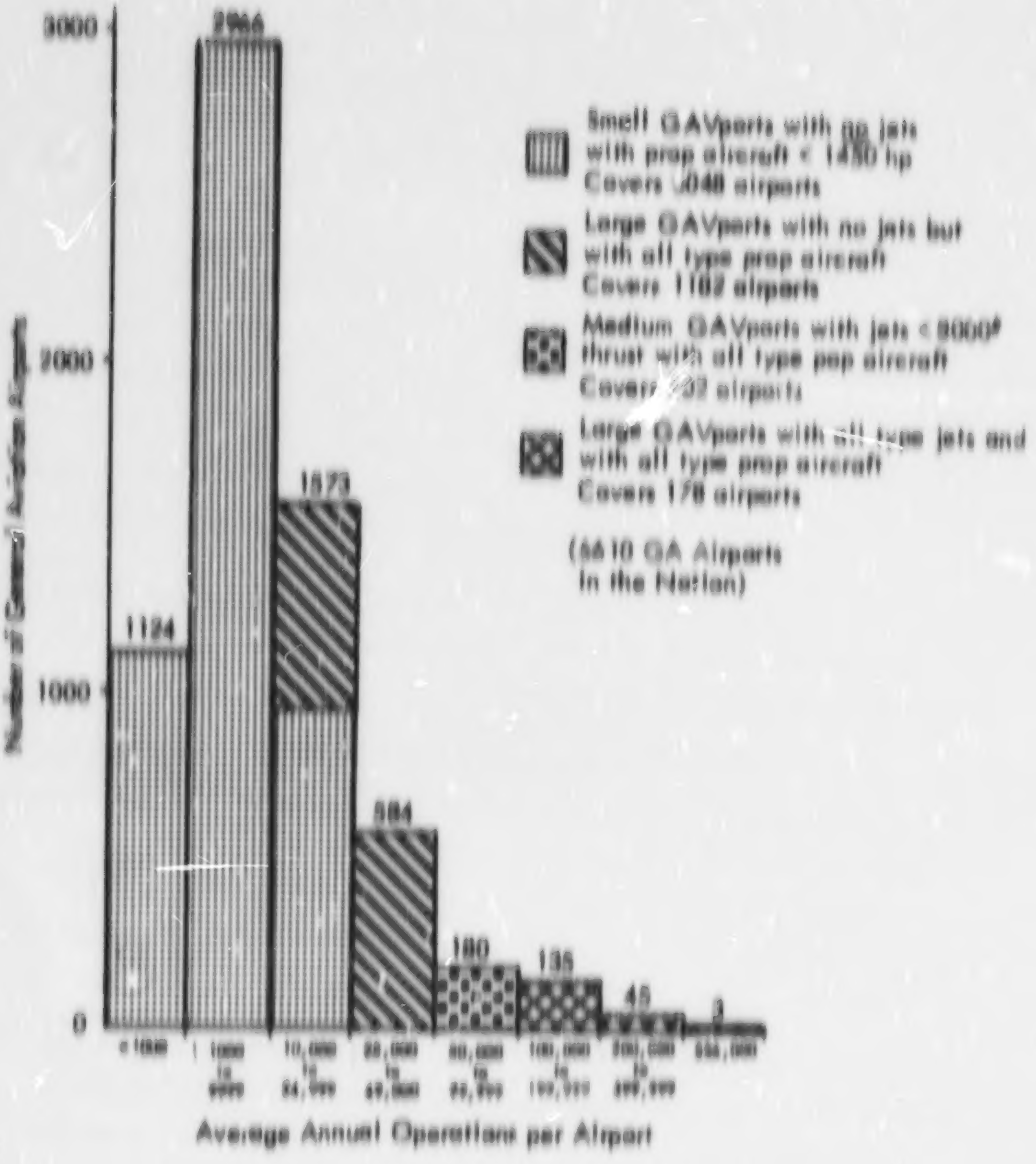

Figure II-2. Estimated Distribution of GAVports for the Nation

Table H-3

Profile of Operations of GA Aircraft[2,6]

Aircraft Type	Percent of National Operations
Small Piston Aircraft { Single engine Multi-engine	87.7
Large Piston Aircraft	8.9
Small Turboprop	0.2
Large Turboprop	0.5
Small Jet	0.4
Large Jet	0.6
Total	100.0%

Finally, from References 2 and 6, an estimate was possible of the relative number of operations of each aircraft type defined in Table H-2. This estimated overall profile is given in Table H-3.

This profile of operations is applicable for the nation, but will vary for each GAVport because not all aircraft types were assigned to each GAVport category. However, use of the GAVport operations distribution (Figure H-2 and Table H-2) and the percentage profile of aircraft types over the nation (Table H-3) enabled calculation of the relative split of aircraft operations by aircraft type for each of the four GAVports. This estimate is presented in Table H-4.

Data on percent of night operations for GA airports are extremely sketchy in the literature. Nevertheless, available information was interpreted with a certain degree of subjectivity to arrive at the night operation percentages needed for the four GAVports.[7,8,9,10] These estimates are listed on the following page.

GAVport Category	Percent of Operations at Night
Large AVport with Jets	5.0
Medium AVport	1.0
Large AVport without Jets	1.0
Small AVport	0.5

Table H-4

Percentage of Operations Per GAVport Category Per Aircraft Type[a]

Small Piston

GAVport Category	Large Jets	Small Jets	Large Piston	Single Engine	Multi-Engine	Large Turboprop	Small Turboprop	Total
Large GAVports with Jets 5% Night Operations	2.0	0.9	0.3	85.7	8.6	0.7	1.8	100
Medium GAVport 1% Night Operations	0	0.9	0.3	87.5	8.6	0.7	1.8	100
Large GAVports without Jets 1% Night Operations	0	0	0.3	88.3	8.9	0.7	1.8	100
Small GAVports 0.5% Night Operations	0	0	0	89.2	9.0	0	1.8	100

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[a] Computed from Figure H-2 and Tables H-2 and H-3.

H.7 AIRCRAFT NOISE AND PERFORMANCE DEFINITIONS

Aircraft noise and performance are dependent on numerous parameters including such factors as power setting, environmental conditions and engine design. For practical purposes, power (or thrust) setting was used to define the noise and performance related to GA aircraft. Therefore, the appropriate horsepower or thrust setting was needed for each aircraft type.

The national fleet of GA aircraft was broken down by aircraft type and horsepower for piston aircraft or thrust for jets.[2] The breakdown of these fleet profiles was condensed into a single number for each aircraft type by calculating the mean horsepower or thrust weighted by the number of that aircraft type in the national fleet. These calculations provided the following mean values of engine power.

Aircraft Type		Weighted Mean Horsepower or thrust
Small Piston	Single engine	189 HP
	Multi-engine	572 HP
Large Piston		4211 HP
Small Turboprop		1164 HP
Large Turboprop		4772 HP
Small Jet		5610 lb thrust
Large Jet		10,585 lb thrust

Utilizing available information from Wyle's data files and from the literature, it was possible to construct estimates of noise and performance curves for each of these aircraft types.[10-15]

Figures H-3, H-4, and H-5 are the noise exposure level (L_{NE}) versus distance curves for the takeoff and approach conditions. Each of these noise curves were based on estimated noise levels according to the above tabulation of aircraft type and weighted mean horsepower or thrust. The business jet noise curves are simplified for application

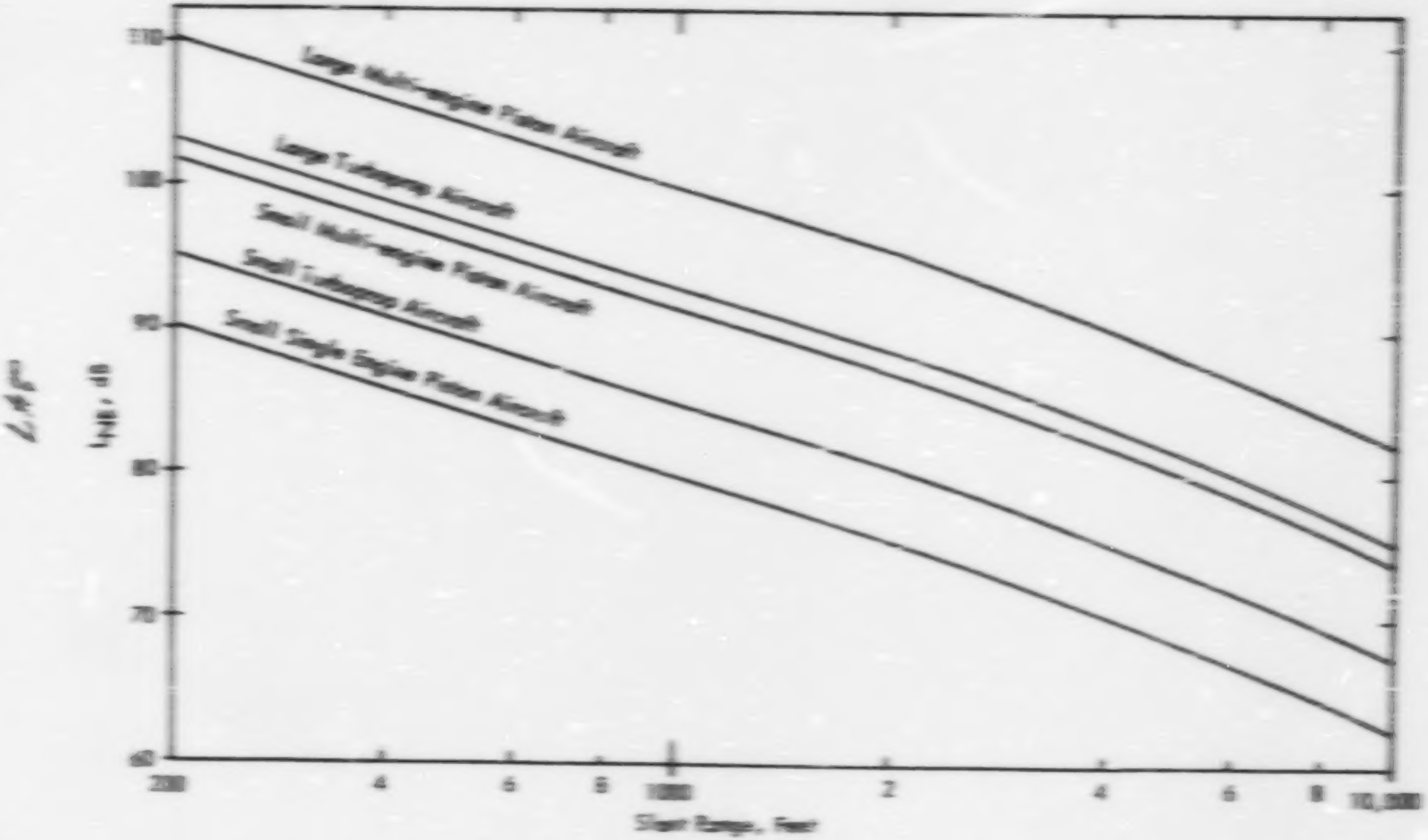

Figure H-2. Takeoff Noise Curves for Prop Aircraft (Reference 11)

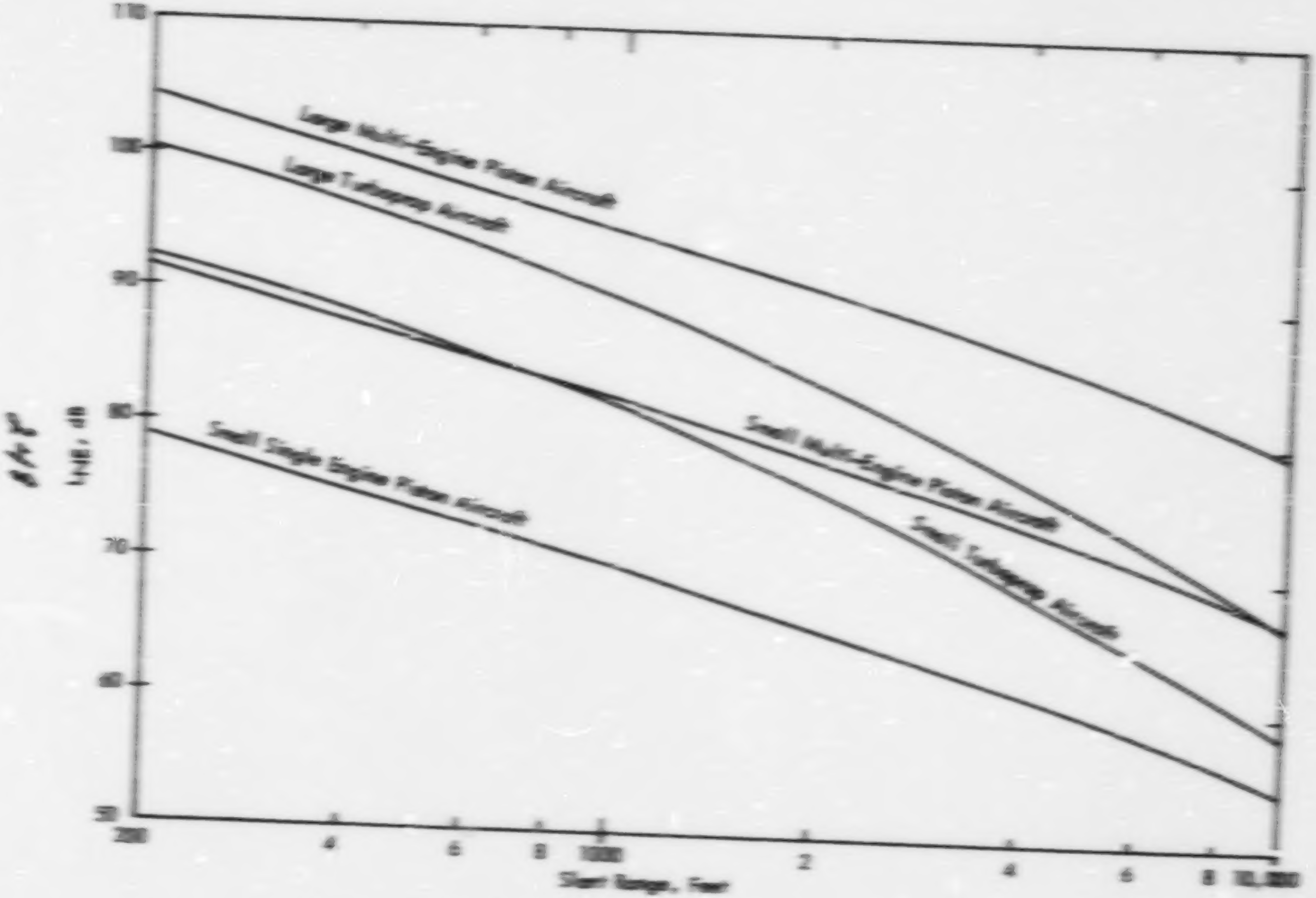

Figure H-4. Approach Noise Curves for Prop Aircraft (Reference 11)

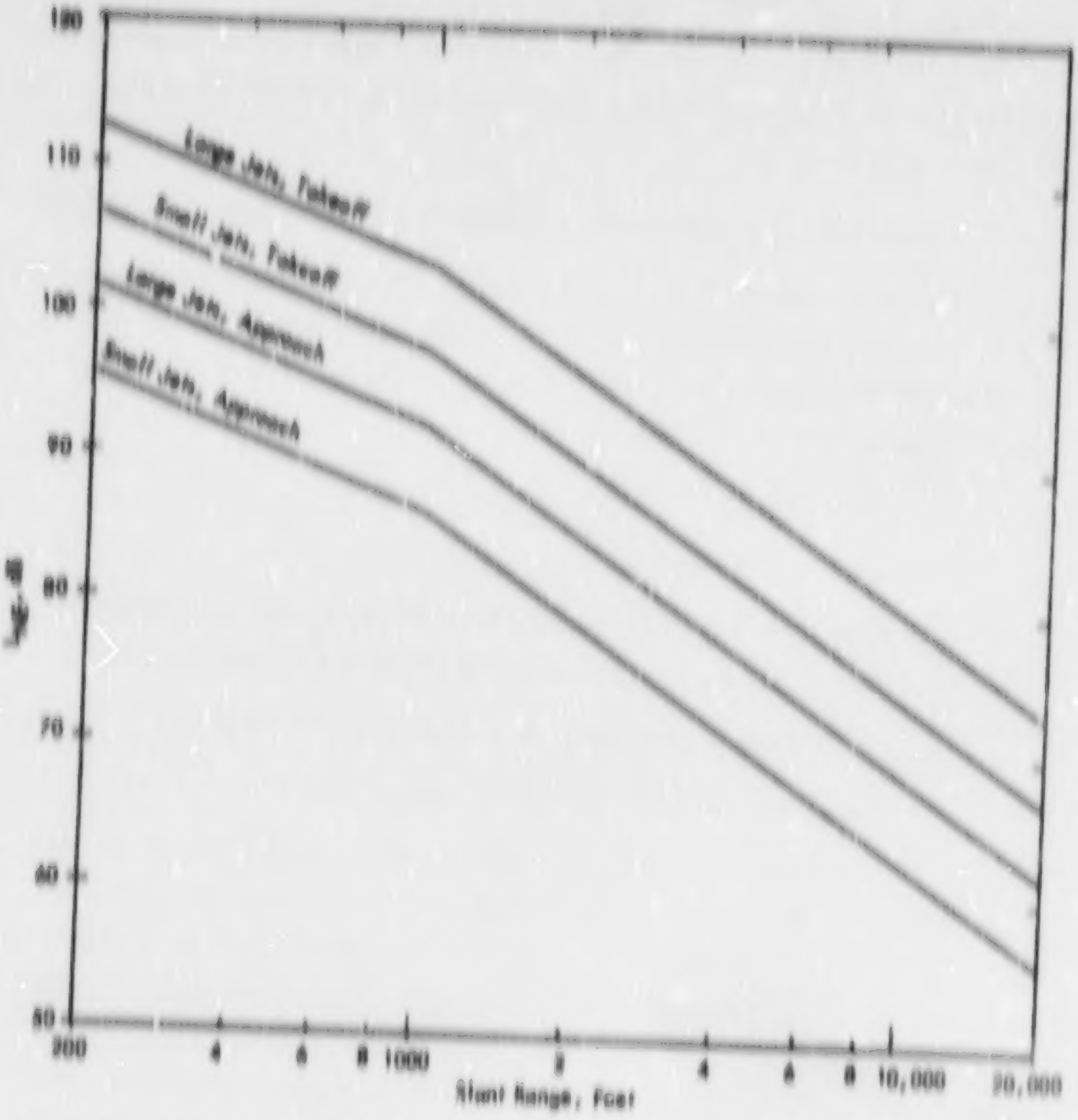

Figure H-5. Takeoff and Approach Noise Curves for Business Jet Aircraft (Adapted from Data in References 10, 12 - 15) to this study. The corresponding takeoff performance curves are plotted in Figures H-6[11] and H-7[16] for prop and jet aircraft respectively. Approach profiles were assumed to have a 5 degree glide slope angle for all prop aircraft and a 3 degree glide slope angle for all jets.

H.8 COMPUTER ANALYSIS OF THE PRESENT NOISE CONTOURS

Following the definition of the four AVports, the L_{dn} contour positions were calculated and the area within the L_{dn} 65, 70, and 75 contours determined. (The L_{dn} 80 and 85 dB contours were too small to be significant for any of the GAVport models.) The required data for each calculation was:

1. Percentage mix of each aircraft type.
2. Total daily operations.
3. Ground track definition and runway utilization. (All operations were assumed along a straight in and straight out path in one direction.)
4. Noise exposure level versus slant range for each aircraft type.
5. Takeoff and approach profile definitions for each aircraft type.

The same computer program used for the air carrier airport analysis was used to execute the contour calculations including the computer routine to sum the area within any designated L_{dn} contour. These areas were plotted against the contour values for the four GAVports, broken down by the operations categories distributed over the nation. Figures H-8, -9, -10, and -11 depict these relations of L_{dn} contour and the enclosed areas for the four GAVports. Each of these figures contains a separate line for the mean value of daily operations for each of the daily operations categories over which the GAVports were spread. (See Figure H-2.)

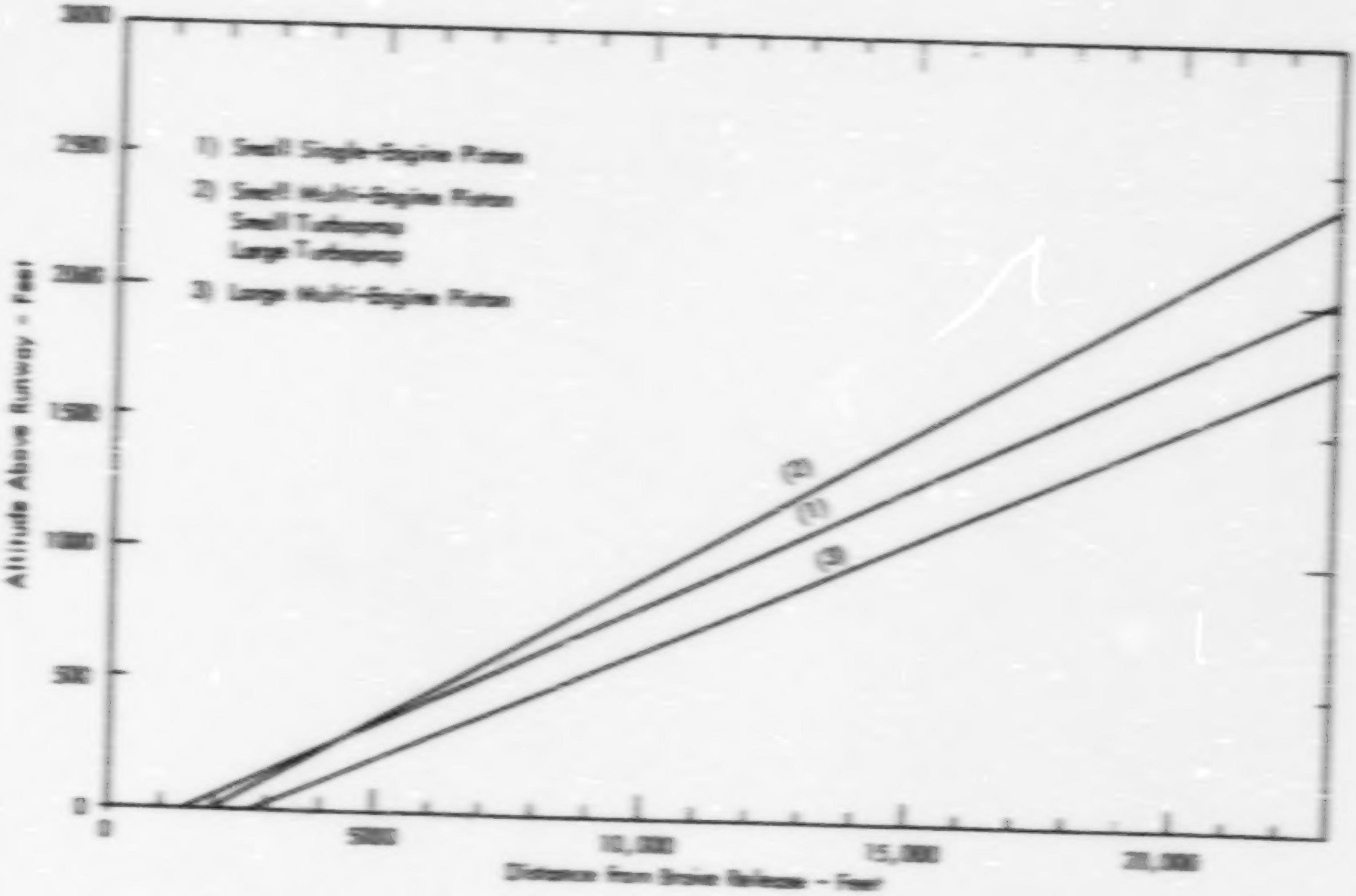

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Figure H-6. Takeoff Performance Characteristics for Propeller Aircraft (Reference 11)

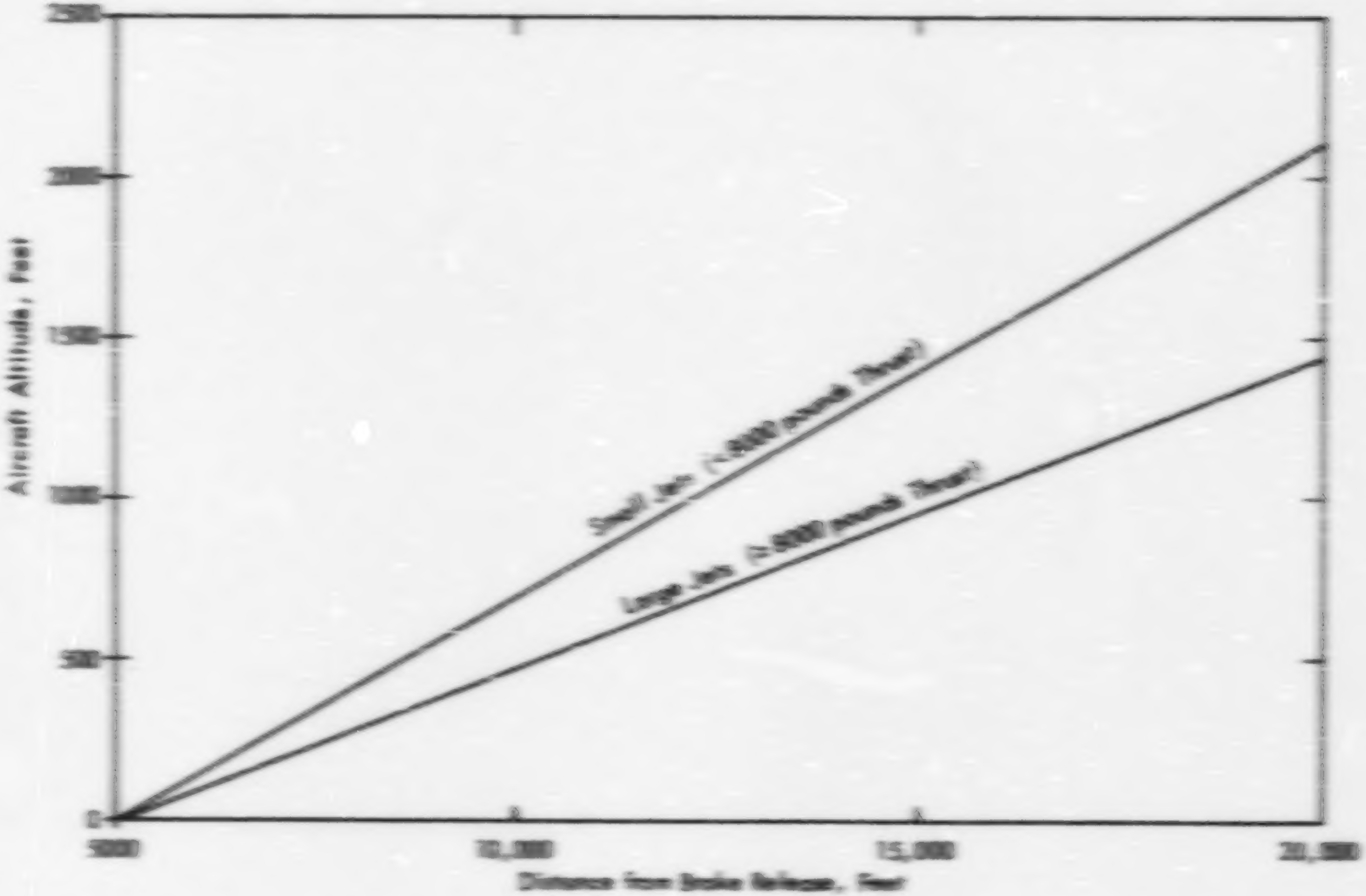

Figure H-7. Takeoff Performance Characteristics for Business Jet Aircraft (Reference 16)

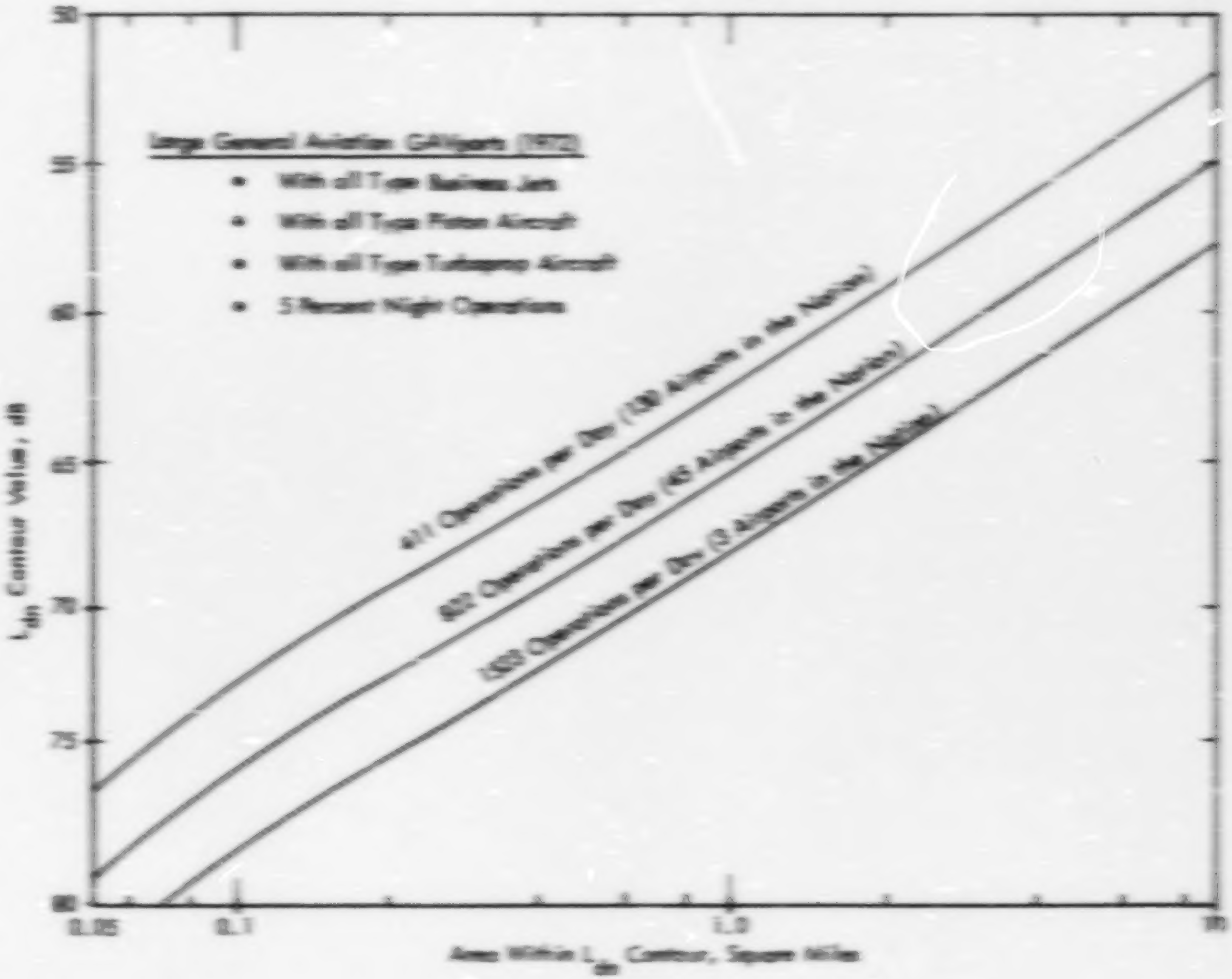

Figure H-8. Contour Area Versus L_{dn} for a Large GAirport with All Types of Business Jets (1972)

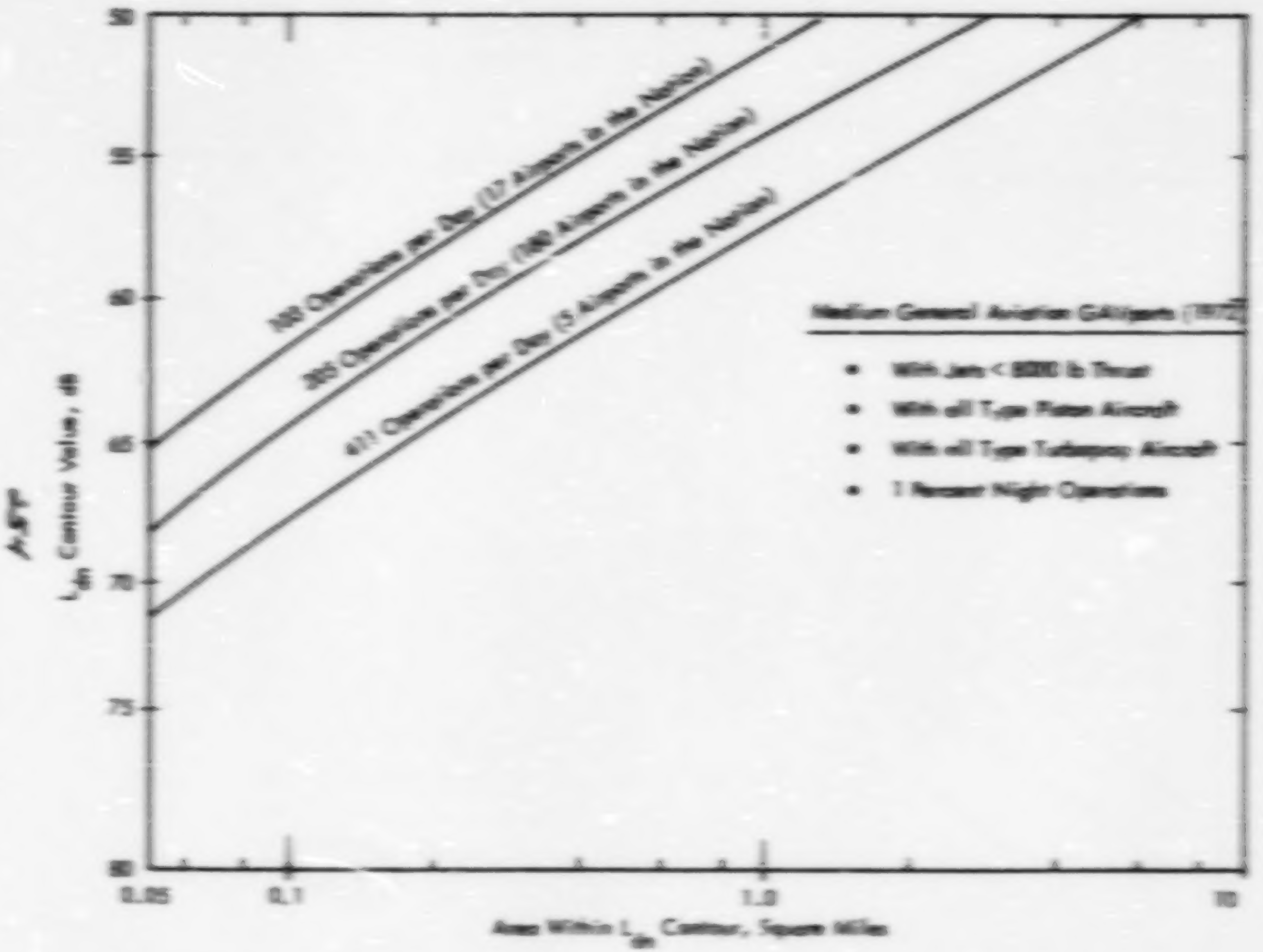

Figure H-9. Contour Area Versus L_{dn} for a Medium GAIrport (1972)

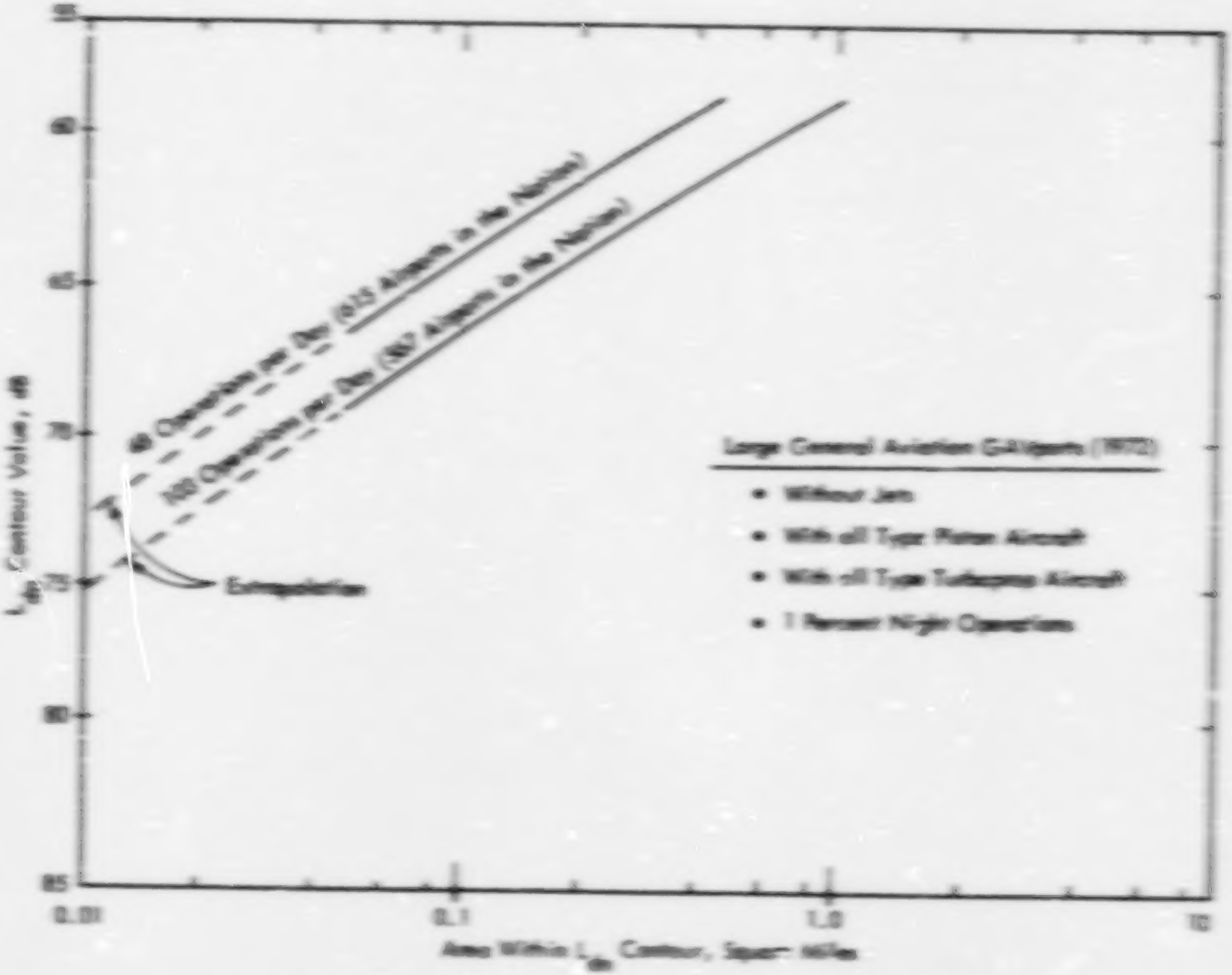

Figure H-10. Contour Area Versus L_{dn} for a Large GAirport Without Business Jets (1972)

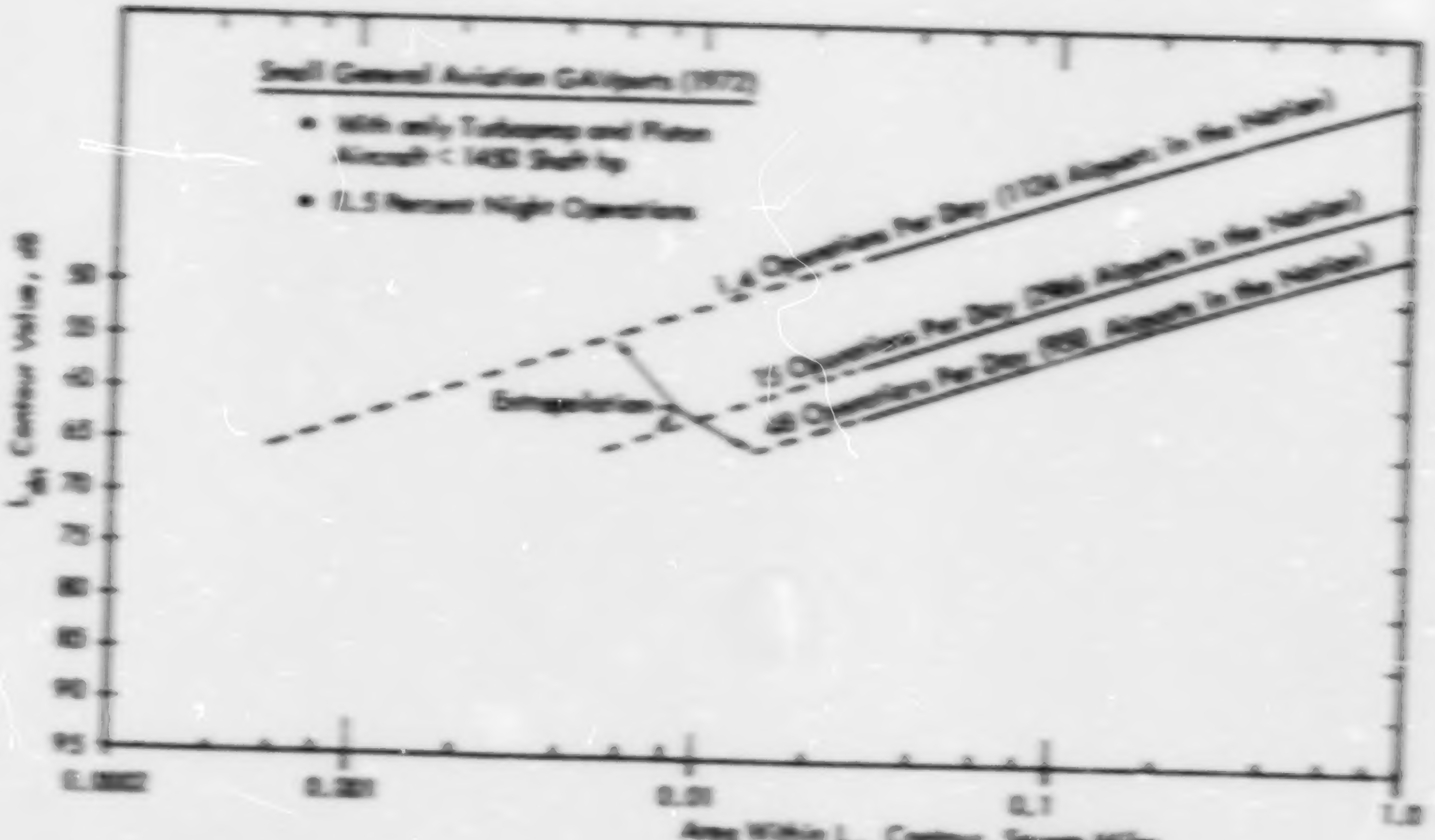

Figure 16-11. Contour Area Versus L_{dn} for a Small GA Airport (1972)

The product of the area per airport within a particular L_{dn} contour and the number of airports in that category summed over the nation gave the total national area within the contour of interest. The resulting estimate of areas encompassed by the L_{dn} contours around all general aviation airports for the present time period are:

L_{dn}, dB	65	70	≥75
Contour Area, sq. mi.	212	71	25

A histogram relating the national area within the L_{dn} 65 contour by GAVport type and operations per airport for 1972 is shown in Figure H-12. This histogram distinctly shows the important influence of business jet noise upon the nation's general aviation airports.

H.9 ESTIMATE OF THE FUTURE NOISE IMPACT

Future noise contours were estimated for 1987 by calculating an appropriate shift in the effective L_{dn} of the 1972 contour values that was equivalent to the change in the future operations. Total national area within each contour was then calculated in the same fashion as described in the previous section.

The change in the future L_{dn} from the present levels was estimated by taking the difference between the future and present energy average L_{dn} over all aircraft types in each GAVport category at a reference condition of takeoff flyover with a 1000 feet slant range. The increase in annual operations used in the calculation of the future L_{dn} values were estimated from projections of future aircraft operations. The annual operations forecast for General Aviation in Reference 6 for 1981 were projected linearly to 1987 enabling estimation of the increase in operations between 1972 and 1987 for each aircraft type. This estimate of aircraft operations increase is shown in Table H-5.

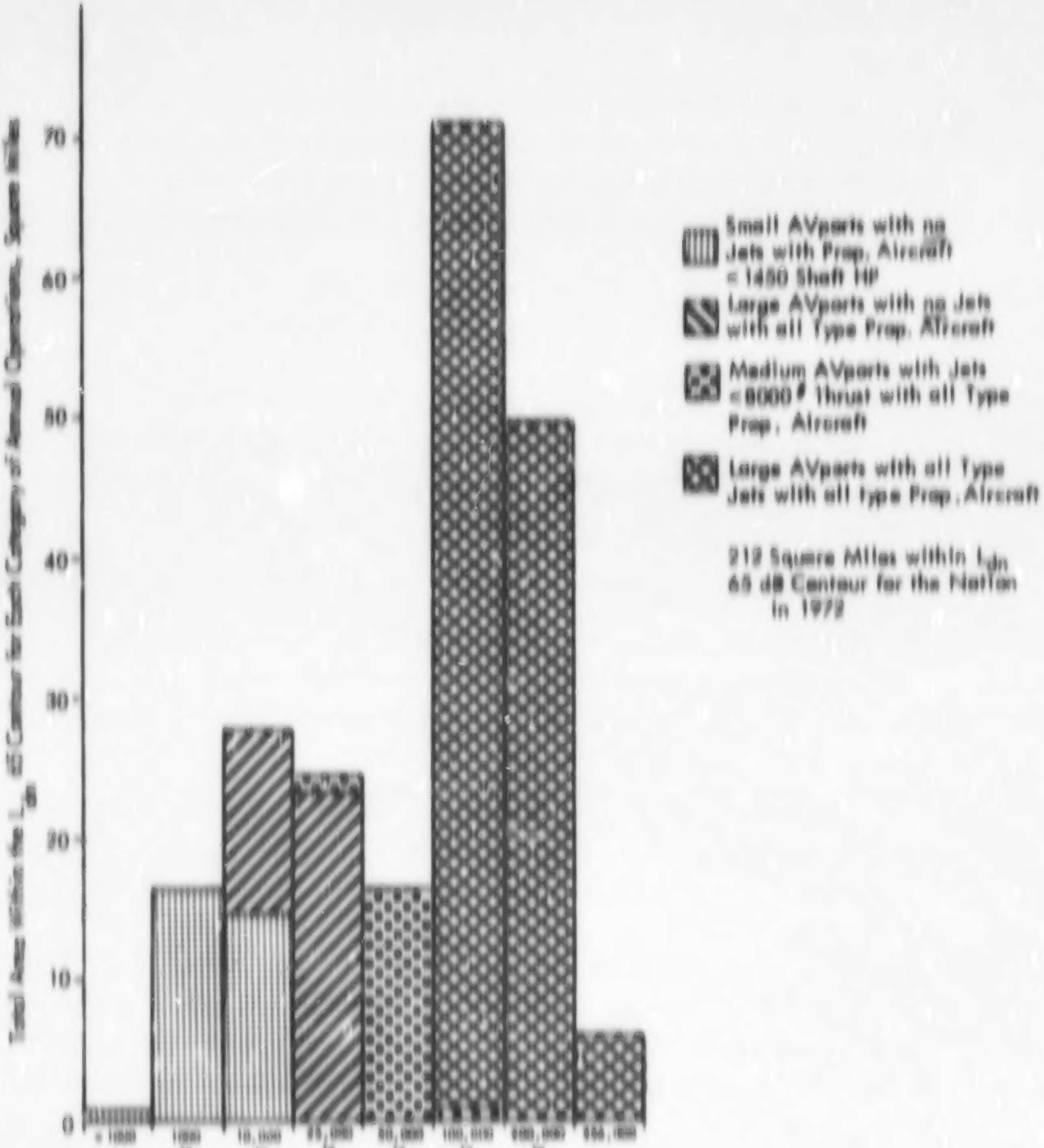

Figure II-12. General Aviation Contour Area Distribution (1972)

Table H-5

Relative Increase in Operations of General Aviation Aircraft From 1972 to 1987 (Extrapolated from Data in Reference 6)

Aircraft Type	Ratio = $\frac{\text{1987 Operations}}{\text{1972 Operations}}$
Small Single Engine Piston	2.0
Small Multi-Engine Piston	2.0
Large Piston	0.4
Small Turboprop	4.0
Large Turboprop	3.2
Small Jets	3.7
Large Jets	3.7

With this procedure, two future cases were examined:

(1987 - Base) Both piston aircraft and jets have the same noise exposure level values in the future as in the present.

(1987 - 5 dB) Piston aircraft noise levels remain constant but business jet noise levels decrease uniformly by 5 dB.

For both the present and future cases, the estimated population impacted by general aviation airport noise and the corresponding noise units were computed using the same prediction equations as for air carrier airports. The appropriate AVtowns (See Section 2.7 in main text) were chosen on the same basis of number of daily operations. The results of this analysis are summarized in Table H-6 and are discussed in more detail at the end of Section 4.

Table II-6

General Aviation Noise Impact

Year	Alternative	Factor	L_{dn} Band, dB 65-70	 70-75	 75-80	Total	Units
1972	Base	Contour Area	141.0	46.0	25.0	212.0	Sq. Mi.
		Population	12.1	0.1	0	12.2	x 1000
		Housing Units	4.5	0.03	0	4.5	x 1000
		Noise Units	7.9	0.09	0	8.0	x 1000
1987	Base	Contour Area	346.0	117.0	60.0	523.0	Sq. Mi.
		Population	170.2	6.17	0.04	176.4	x 1000
		Housing Units	63.0	2.06	0.01	65.1	x 1000
		Noise Units	112.6	5.6	0.05	118.3	x 1000
1987	5 dB Reduction for Business Jet Fleet	Contour Area	221.0	77.0	40.0	338.0	Sq. Mi.
		Population	52.2	1.02	≈ 0	53.3	x 1000
		Housing Units	19.3	0.34	≈ 0	19.6	x 1000
		Noise Units	34.5	0.93	≈ 0	35.4	x 1000

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APPENDIX I

BACKGROUND AND SUPPORT DATA

Table I-1

AVIATION ACTIVITY FORECASTS

		1978	1981	1987
Fleet				
Wide Body				
4 Engine		225	310	502
3 Engine		300	470	951
2 Engine		300	470	951
Narrow Body				
4 Engine		398	346	295
3 Engine		989	1036	775
2 Engine		576	596	492
Prop		240	150	78
3D/8D Included (Not Retrofitted)				
DC-8	3D	398	346	170
B-707		398	792	440
B-727		792	792	440
B-737		501	501	407
DC-9		501	501	407
Demand Forecast (National Total)				
Enplaned Passengers x 10^6		239.5	274	322
Rev. Passenger Miles(1)		378	487	664
Aircraft Operations x 10^6		10.9	11.4	11.1

Note (1) Total scheduled domestic + international + non-sched RPM of U.S. air carriers (estimated)

Table I-2
PLANNING FACTORS USED

1978	Passengers Enplanements $x\ 10^6$	Operations Per Year $x\ 10^6$	Capacity (SEATS)
Wide Body		$x\ 10^6$	
4 Engine	25.2	0.45	335
3 Engine	40.6	0.90	260
2 Engine	40.6	0.90	260
Narrow Body			
4 Engine	18.7	0.88	130*
3 Engine	97.2	4.55	123
2 Engine	50.1	3.17	91
Prop	6.7	0.96	40

*Average of standard and stretch

1981		
Wide Body		
4 Engine	36.0	0.62
3 Engine	63.6	1.41
2 Engine	63.6	1.41
Narrow Body		
4 Engine	16.3	0.76
3 Engine	101.8	4.77
2 Engine	51.8	3.28
Prop	4.2	0.60

1987		
Wide Body		
4 Engine	58.4	1.00
3 Engine	128.6	2.85
2 Engine	128.6	2.85
Narrow Body		
4 Engine	13.9	0.65
3 Engine	76.2	3.57
2 Engine	42.8	2.71
Prop	2.2	0.31

Table I-3

AVport II Sample - Annual Operations

Departures by Aircraft Type

		B-727	BAC-111 B-737	DC-9	Turboprop
Fort Smith	(FSM)	813	0	0	5067
Bakersfield	(BFL)	812	973	0	876
Bradford	(BFD)	0	0	2810	430
Santa Barbara	(SBA)	1839	0	1840	14
Pueblo	(PUB)	858	865	0	653
Daytona Beach	(DAB)	30	327	0	2429
Savannah	(SAV)	3700	0	2213	7
Champaign/Urbana	(CMI)	0	0	3076	3283
Decatur	(DEC)	0	6	1390	1401
Ft Wayne	(FWA)	501	2202	2172	0
Alexandria	(ESF)	0	0	2363	1862
Bangor	(BGR)	1259	0	873	0
Flint (Bishop)	(FNT)	469	1410	0	2557
Meridian	(MEI)	0	0	2168	359
Manchester	(MHT)	0	0	1858	55
Jamestown	(JHW)	0	0	0	2140
Youngstown	(YNG)	643	1548	0	2004
Lawton/Ft Sill	(LAW)	0	3	713	2561
Eugene	(EUG)	0	1924	1780	7
Medford	(MFR)	19	1407	924	103
Wilmington	(ILM)	5	0	3537	2282
Scranton/Wilkes-Barre	(AVP)	494	0	1157	1188
Rapid City	(RAP)	4	3593	368	1175
Abilene	(ABI)	0	0	1280	1244
Burlington	(BTV)	33	3045	1114	455
Staunton	(SHD)	0	0	0	2291
Parkersburg	(PKB)	0	0	0	3300
Oshkosh/Appleton	(OSH)	0	0	652	4071
Cheyenne	(CYS)	3	715	0	2117
Yakima	(YKM)	0	0	2189	1771

Note 1: Same for arrivals.
Note 2: Refer to Progress Report - April 4-May 30, 1975.

Table I-4

AVport II - Sample

Average Daily Night Arrivals for 18 Airports

		727	737	DC-9	Turboprop
Fort Smith	(FSM)	1	-	-	-
Bakersfield	(BFL)	0	0	0	0
Santa Barbara	(SBA)	0	0	0	0
Pueblo	(PUB)	-	1	-	1
Savannah	(SAV)	-	-	1	-
Decatur	(DEC)	-	-	2	1
Champaign/Urbana	(CMI)	-	-	1	-
Ft Wayne	(FWA)	1	1	-	-
Bangor	(BGR)	2	-	1	-
Flint (Bishop)	(FNT)	0	0	0	0
Manchester	(MHT)	-	-	1	-
Youngstown	(YNG)	1	-	-	-
Eugene	(EUG)	0	0	0	0
Harrisburg		-	-	1	-
Rapid City	(RAP)	0	0	0	0
Burlington	(BTV)	-	-	-	2
Parkersburg	(PKB)	0	0	0	0
Cheyenne	(CYS)	-	-	-	2

Note 1: Same for Departures.

Note 2: Assume 10 percent night operations for all AVport II Sample Airports.

Table I-5

AIRPORT III (MID-RANGE) SAMPLE

ARRIVALS BY AIRCRAFT TYPE

CITY		DC-9	B-737	B-727	B-707	DC-8	L-1011	DC-10	TURBO	747
		BAC-111/			B-720/					
		D N	D N	D N	D N	D N	D N	D N	D N	D N
Huntsville	(HSV)	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	
Mobile	(MOB)	[illegible]		[illegible]		[illegible]			[illegible]	
Anchorage	(ANC)		[illegible]	[illegible]	[illegible]				[illegible]	
Tucson	(TUS)	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]
Little Rock	(LIT)	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]
W Palm Beach	(PBI)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	
Lihue	(LIH)	[illegible]	[illegible]						[illegible]	
Kahului	(OGG)	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	
Springfield	(SPI)	[illegible]							[illegible]	
Cedar Rapids	(CID)	[illegible]	[illegible]	[illegible]					[illegible]	
Des Moines	(DSM)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	
Wichita	(ICT)	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	
Shreveport	(SHV)	[illegible]	[illegible]						[illegible]	
Grand Rapids	(GRR)	[illegible]	[illegible]	[illegible]					[illegible]	
Jackson	(JAN)	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	
Billings	(BIL)			[illegible]	[illegible]				[illegible]	
Albany	(ALB)	[illegible]				[illegible]			[illegible]	
Fayetteville	(FAY)		[illegible]						[illegible]	
Greensboro	(GSO)	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	
Providence	(PVD)	[illegible]	[illegible]	[illegible]					[illegible]	
Charleston	(CHS)	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	
Columbia	(CAE)	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	
Sioux Falls	(FSD)	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	
Chattanooga	(CHA)	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	
Knoxville	(TYS)	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	
El Paso	(ELP)	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	
Lubbock	(LBB)	[illegible]	[illegible]	[illegible]					[illegible]	
Midland	(MAF)	[illegible]		[illegible]	[illegible]				[illegible]	
Norfolk	(ORF)	[illegible]	[illegible]	[illegible]					[illegible]	

Note 1: Same for Departures.

Note 2: Average Night Operations = 10%.

Note 3: Refer to Progress Report, 20 August 1975, Enclosure "A".

Note 4: The average percent stage length distribution used (based on airline schedules) was as follows:

	Stage Length in Nautical Miles			
	0-500	500-1000	1000-1500	>1500
Percent Distribution	83%	6%	6%	5%

Table I-6

Land Use Inside 30 NEF (mi^2)

	Residential Land	Nonresidential Land	Water Area	Airport Property	Total
Atlanta	11.50	89.5	0	6	107
Boston	27.70	5.3	42	2	77
Buffalo	11.90	26.4	0	1	39
Chicago-Midway	2.87	3.1	0	1	7
Chicago-O'Hare	63.3	109.7	0	10	183
Cleveland	11.34	25.7	0	2	39
Denver	10.36	16.7	0	6	33
Dulles	0.14	12.9	0	11	24
JFK	38.7	14.3	128	7	188
La Guardia	25.25	7.8	8	1	42
Los Angeles	23.10	4.9	63	6	97
Miami	21.95	30.0	13	4	69
Minneapolis	11.05	13.0	3	4	31
Newark	32.14	53.9	11	3	100
New Orleans	3.30	22.7	6	2	34
Philadelphia	9.06	8.9	15	3	36
Phoenix	3.01	7.8	0	3	13
Portland	0.72	10.3	6	3	20
San Diego	6.46	5.5	5	1	18
San Francisco	9.90	12.1	50	4	76
Seattle	17.50	24.5	2	3	47
St. Louis	10.06	18.0	0	2	30
Washington National	4.02	3.8	6	1	14
	363	[illegible]	[illegible]	85	[illegible]

Table 1-7

Day/Night Split, Equivalent Daily Operations and Impact Area for the Three Airports

	JET D	JET N	PROP D	PROP N	EQUIV(1) OPS	Area(2) L_{dn} 65
AIRPORT I	438.7	72.9	30.7	1.7	1172.8	51.25
II	9.7	2.6	5.32	2.00	41.1	2.50
III	49.3	5.0	11.8	2.0	102.1	5.23
ATL	403	125	38	4	1658.8	107
BOS	243	41	10	0	634.6	77
BUF	63	8	11	0	164.1	38
MDW	49	4	4	0	89.4	7
ORD	617	107	67	5	1698.7	180
CLE	149	16	18	0	310.8	39
DEN	213	17	38	1	387.0	41
IAD	73	9	2	0	162.2	24
JFK	319	117	1	0	1489.1	180
LGA	353	28	16	1	285.6	43
LAX	411	86	12	0	1270.2	97
MIA	228	64	8	0	868.0	69
MSP	134	10	17	0	315.7	31
EWR	181	44	13	1	623.3	100
MSY	113	21	14	2	326.4	34
PHL	190	23	15	0	571.5	36
PHX	80	7	18	1	168.0	13
PDX	96	8	7	0	176.7	20
SAT	96	8	8	0	176.0	18
SFO	303	47	28	0	795.0	76
SEA	138	25	5	0	378.5	47
STL	183	25	39	4	469.9	30
DCA	251	8	49	0	255.9	16
Total	2856	870	388	19	13,481.8	1203

*Arrivals = 1/2 Operations

Note (1) Equiv Ops = N_D(Jets) + 10 · N_N(Jets) + 0.1 × [N_D(Props) + 10 · N_N(Props)]

Note (2) Total Contour Area Inside NEF 30

Table I-8

AVtown Population Densities – A Summary*

Radius	0-1	1-2	2-3	3-4	4-5	5-7	7-9	9-11	11-13	13-15	15-18	18-21
	AVtown I											
315°-45°	122	1805	2830	3282	3366	3198	2374	2179	1923	1568	1210	859
45°-135°	434	2202	2559	3226	2912	2383	1769	1778	1519	1083	742	595
135°-225°	107	2014	3124	3141	3108	3330	3127	2202	1871	1306	774	428
225°-315°	400	2326	4031	4464	4513	3460	2294	1554	1249	997	833	574
Avg (0-360°)	266	2087	3136	3528	3475	3093	2391	1928	1640	1238	715	614
	AVtown II											
315°-45°	190	686	776	776	834	606	337	149	50	51	54	45
45°-135°	89	714	713	647	605	381	201	98	57	34	40	22
135°-225°	850	850	789	653	518	345	247	189	116	68	35	32
225°-315°	374	606	486	507	537	391	159	96	92	68	37	48
Avg (0-360°)	239	714	691	646	624	431	236	133	79	55	42	37
	AVtown III											
315°-45°	125	868	805	803	806	828	766	465	437	347	226	140
45°-135°	460	1087	1105	1029	816	613	703	639	536	429	295	210
135°-225°	358	1131	1516	1384	1126	794	499	332	224	149	158	116
225°-315°	271	1364	1010	1151	1176	1007	851	733	464	356	262	207
Avg (0-360°)	304	1113	1109	1092	901	811	705	542	415	320	235	168

*Note: Basis for values of population density (average and mean in 90° quadrants) plotted on Figure 2-19 versus radius. Relative values (re: maximum) plotted in Figure 2-22.

Table I-9

"Circular Contour" Population Versus Area

Outer Radius Miles	A_T "Contour" Area Square Miles	P, Cumulative Population, Thousands AVtown I	AVtown II	AVtown III
1	3.14	0.83	0.75	0.95
2	12.6	20.5	7.48	11.4
3	28.3	69.8	18.3	28.9
4	50.3	147.4	32.5	52.9
5	78.5	245.6	50.2	80.6
7	153.9	478.8	82.6	141.7
9	254.5	719.2	106.4	212.6
11	380.1	961.5	123.1	280.7
13	530.9	1208.9	135.0	343.3
15	706.9	1426.7	144.7	399.7
18	1017.9	1649.1	157.7	472.8
21	1385.4	1874.7	171.2	534.7

Table I-10

"Single Runway" Contour Areas and Population

Airport	L_{dn} dB	$A_T^{(1)}$ mi^2	$P^{(2)}$ x 1000
I	65	51.2	91.3
	70	19.3	38.9
	75	7.63	15.0
	80	3.26	5.12
	85	1.38	1.66
II	65	2.50	1.27
	70	0.91	0.31
	75	0.35	0.068
III	65	5.23	4.82
	70	2.02	2.05
	75	0.75	0.45
	80	0.32	0.048

Note (1) Total area inside 1972 L_{dn} contours using single runway model.

Note (2) Total population inside L_{dn} contours based on integration of area of contour in annular segments and average population density in corresponding annulus.

APPENDIX J
GLOSSARY OF SIGNIFICANT TERMS

AVport

A statistically average airport representative of airport operational activity within the U.S.

FAR-36

Part 36 of the Federal Aviation Regulations which specifies noise emission standards for subsonic transport aircraft, jet aircraft of new design, and newly produced aircraft of older design.

FAR-36-10

Assumed feasible noise emission limits for aircraft which are 10 dB below Part 36 of the Federal Aviation Regulations.

L_{dn}

The A-weighted average sound level in decibels (day-night average sound level, abbreviated L_{dn}) during a 24-hour period with a 10 dB weighting applied to nighttime noise levels to account for increased sensitivity of people to noise at night.

L_{NE}

Noise Exposure Level, time-integrated values of maximum A-weighted noise levels required for the computation of L_{dn}.

NU

Noise Unit - a scale defining the equivalent number of people exposed to a uniform total L_{dn} value, 20 dB above the criterion noise level around an airport. The criterion is equal to an L_{dn} of 55 dB or the estimated ambient L_{dn} based on population density, whichever is higher. Noise Unit (NU) is currently identified by EPA as Equivalent Noise Impact (ENI).

APPENDIX J (Continued)

SAM

Sound Absorption Materials – Installation of SAM in an engine nacelle for the purpose of source noise control.

REFAN

Source noise control option involving modification and replacement of fan engine components as well as nacelle components.